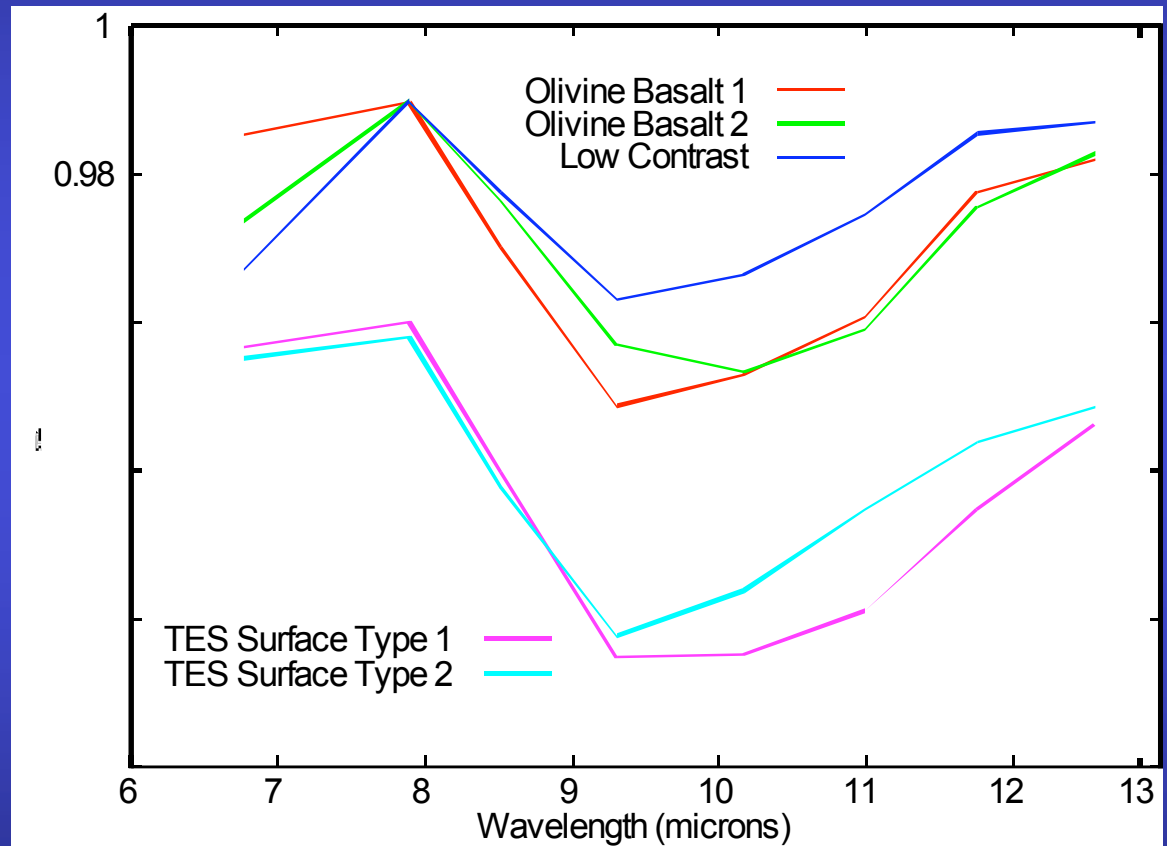


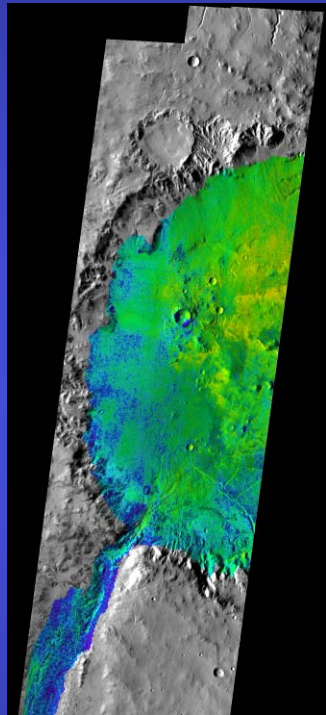
Holden Crater THEMIS spectral endmembers

- Olivine Basalt 1 surface is similar to TES Surface Type 1
- Olivine Basalt 2 surface is consistent with lower silica content due to increased olivine and/or pyroxene
- Low contrast surfaces represent varying contributions from dust or particle size/surface texture

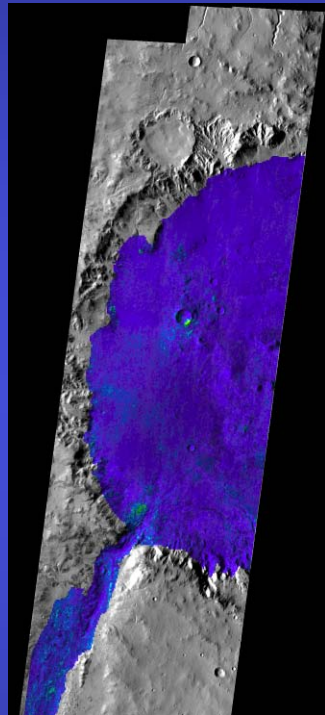


Holden crater

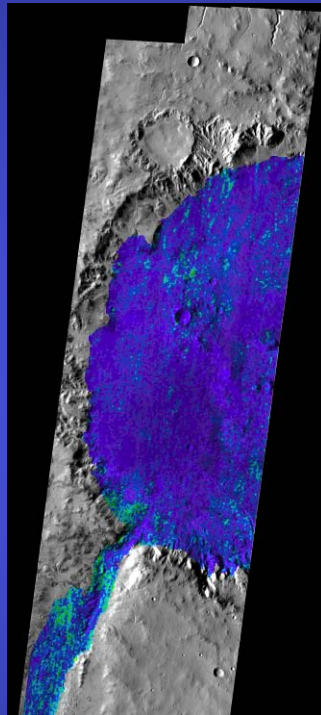
THEMIS spectral unit mosaics



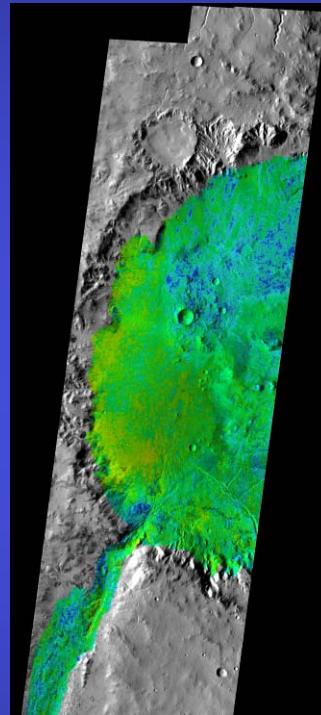
Olivine basalt 1
(0-1.5)



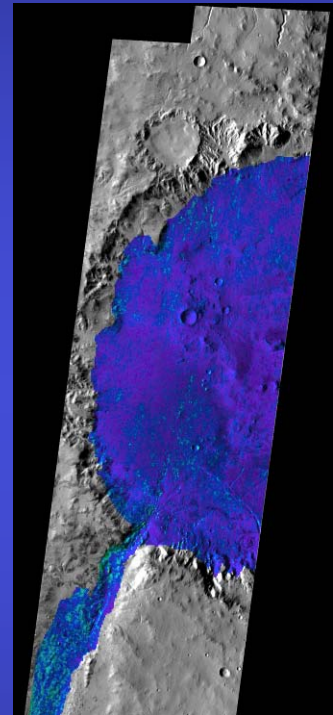
Olivine basalt 2
(0-1.5)



Dust (0-1.5)



Blackbody
(-1 1)

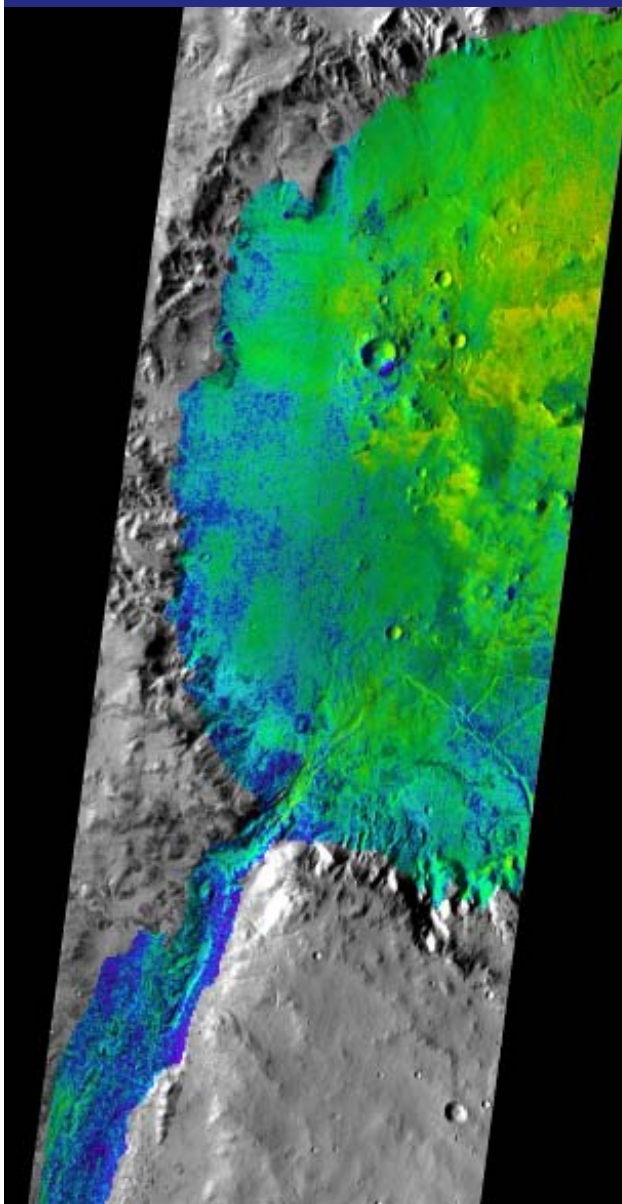


RMS Error
(0-0.005)

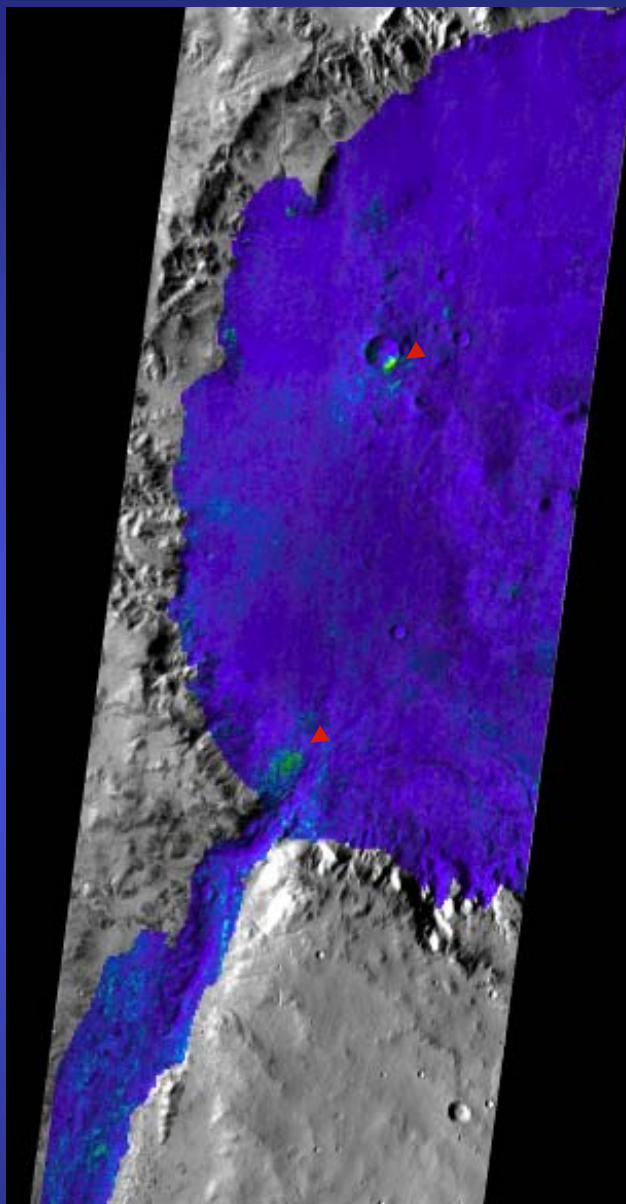


Data above -1000 m excluded

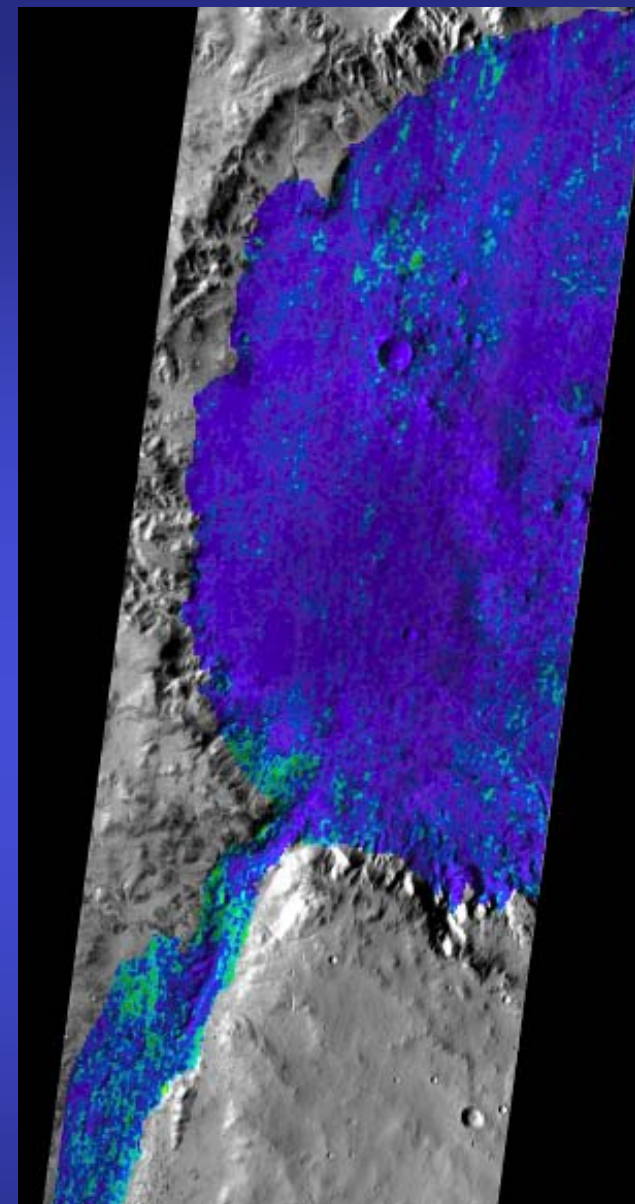
Holden crater



Olivine basalt 1 (0-1.5)



Olivine basalt 2 (0-1.5)



Dust (0-1.5)

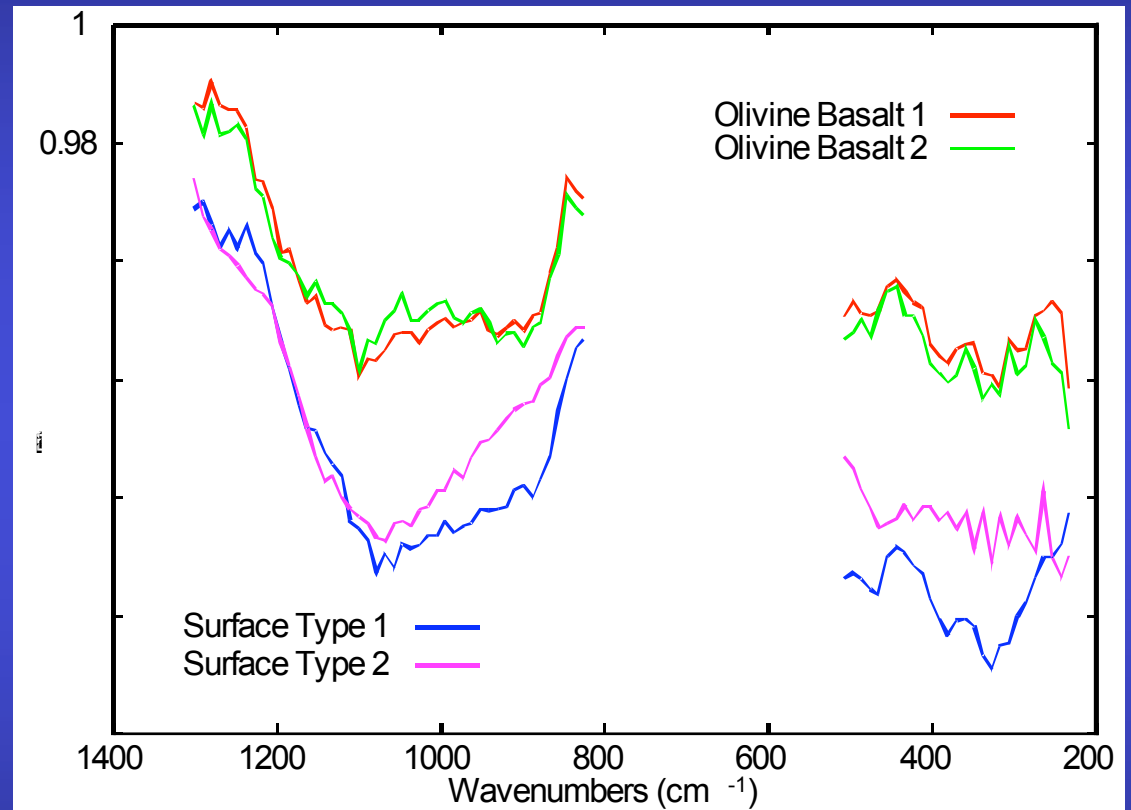
Data above -1000 m excluded



Holden crater

TES analysis of THEMIS spectral units

- All surfaces have significant plagioclase, pyroxene, and olivine (~15-35%)
- Pyroxene and sulfates/high-silica phases are inversely correlated
 - Consistent with slight aqueous alteration?
 - Sulfate detection is questionable, but not unreasonable
 - Landing ellipse is similar to Olivine Basalt 1 (plagioclase, pyroxene, olivine, sulfates, high-Si phases)



Holden crater

Summary

- Two units with compositions similar to olivine basalt are present within Holden crater
 - Most surfaces also have significant high-silica phases
 - Minor unit with higher mafic abundances has likely experienced less alteration
- Dust is not significant throughout most of the region
 - Various spectral contrast may indicate different textural properties (e.g. clean sands versus poorly sorted soils)
 - Isolated regions (e.g. near the crater rim) may have elevated dust cover

VIS-NIR can be used to distinguish between major phyllosilicate groups:

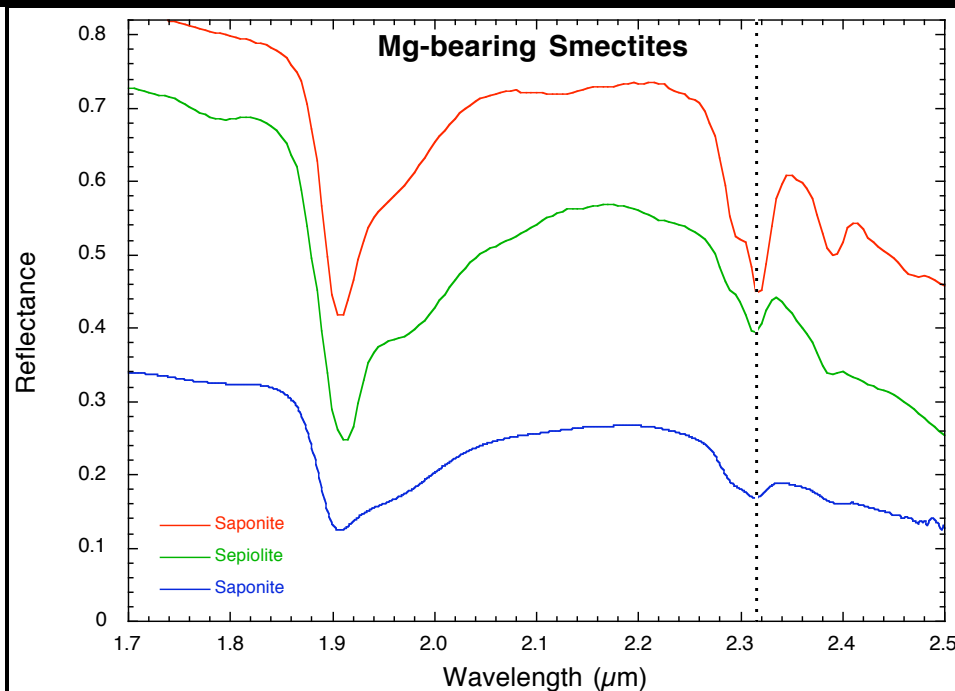
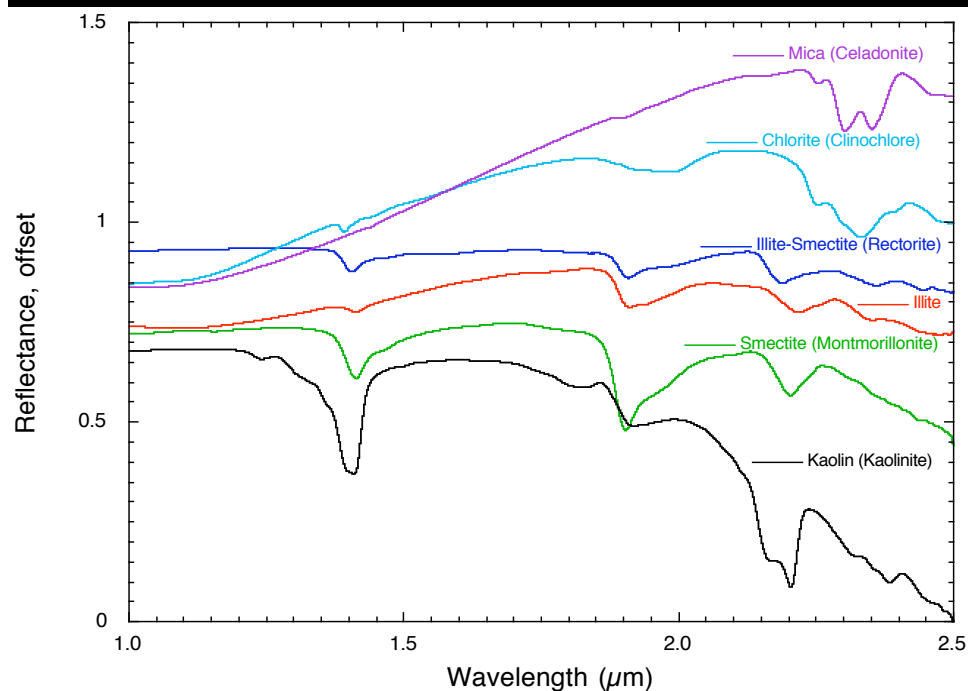
- smectite, mica/illite, chlorite, kaolinite, serpentine

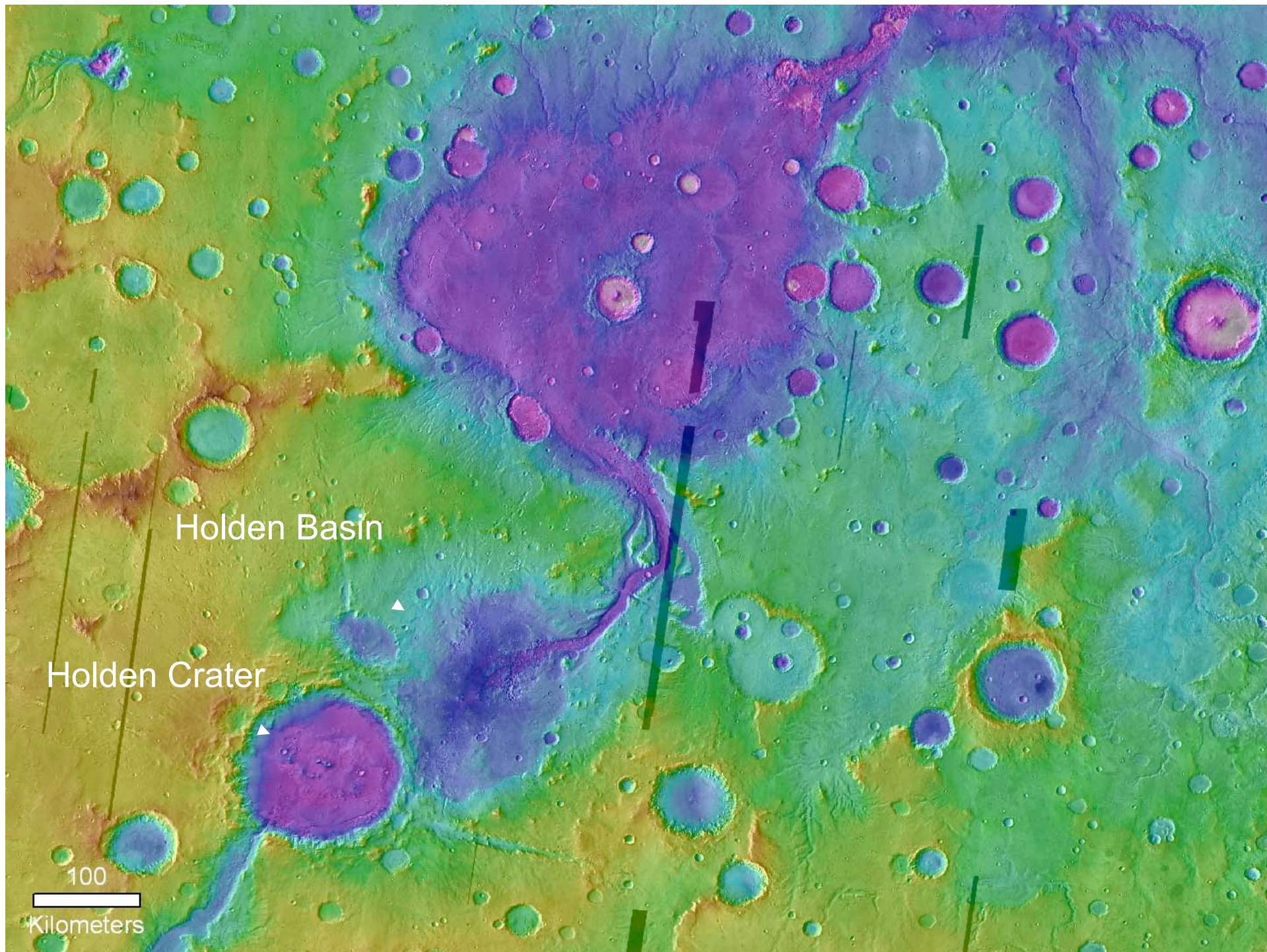
Potential sources of confusion:

- saponite & nontronite with $\text{Fe}^{+2,+3}$ -Mg substitutions (*trioctahedral* vs. *dioctahedral*)
- illite & muscovite (but other micas are spectrally distinct)
- physical mixtures of clays versus mixed-layered clays? (TBD)
- sepiolite versus Mg-bearing smectites such as saponite

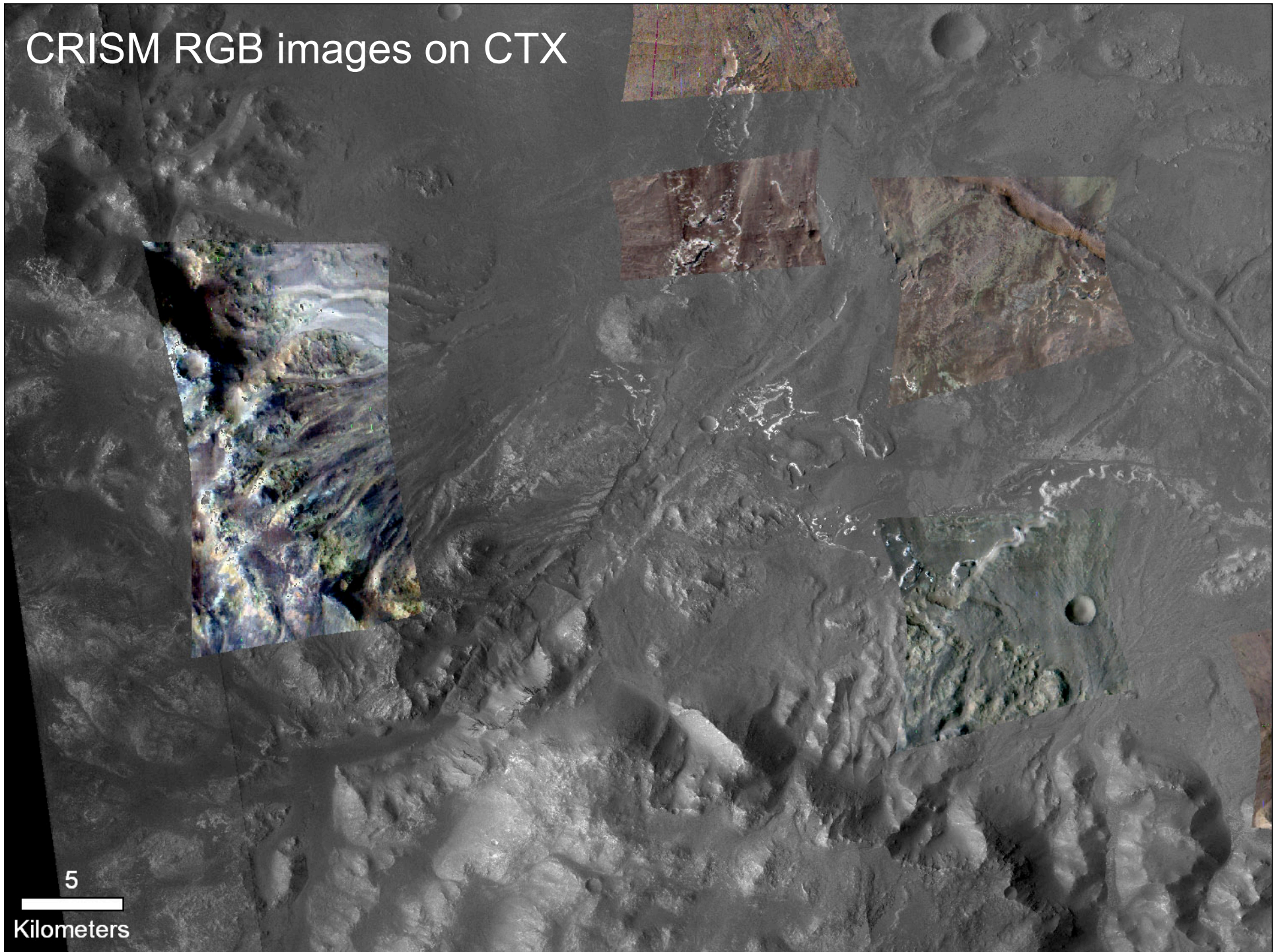
These factors must be kept in mind when using specific clay minerals to determine formation and deposition environments.....

....have we already detected evidence for alkaline lakes and not realized it?

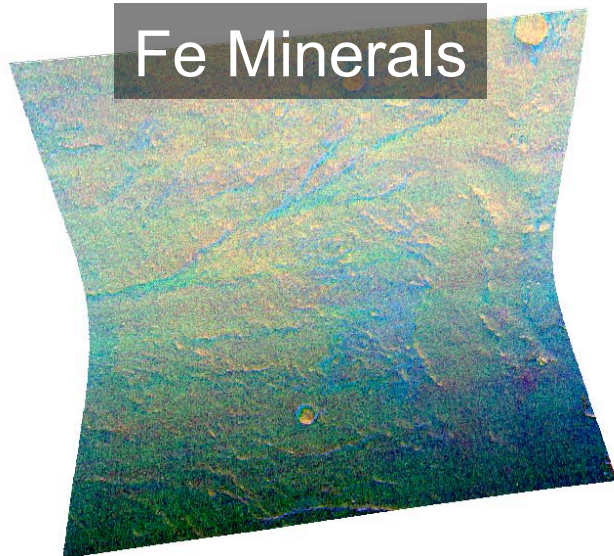




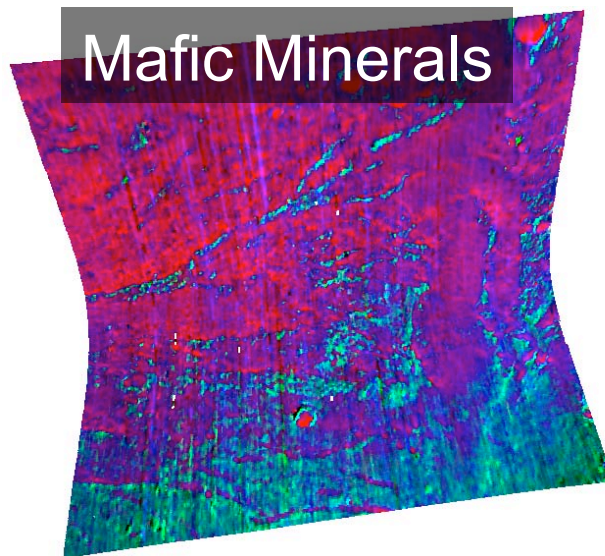
CRISM RGB images on CTX



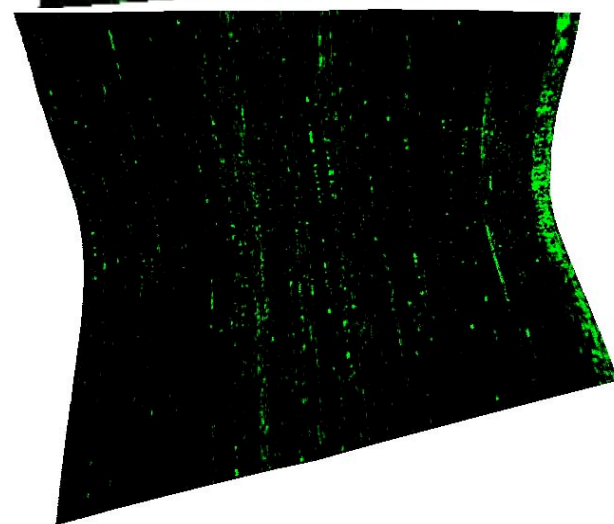
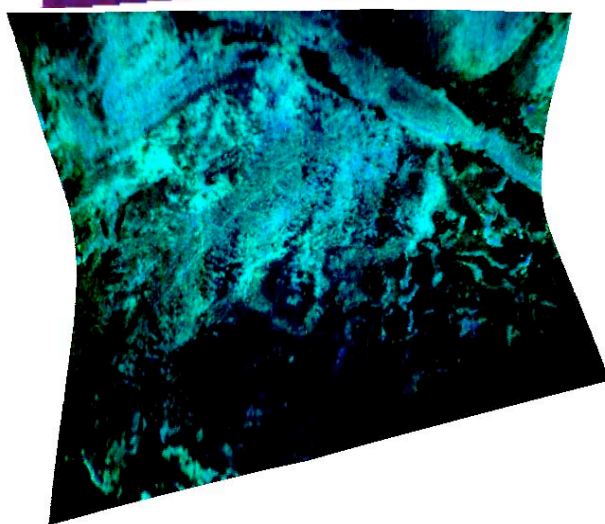
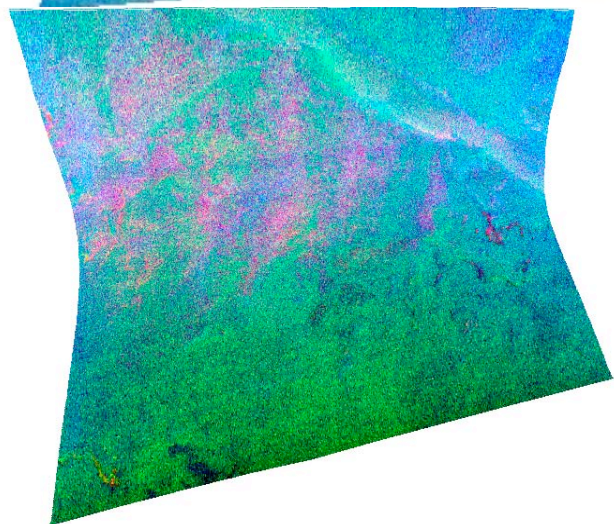
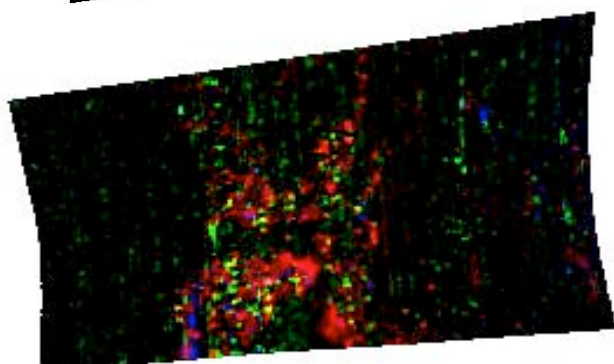
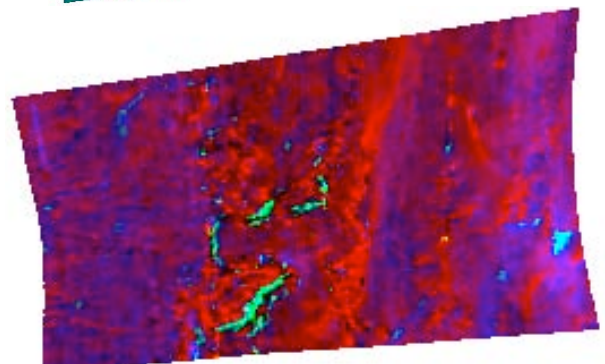
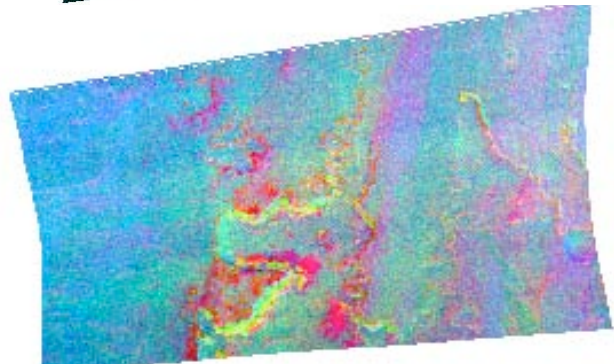
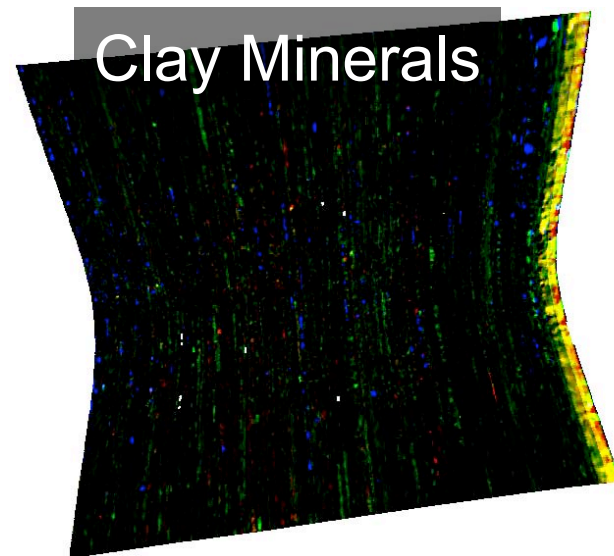
Fe Minerals

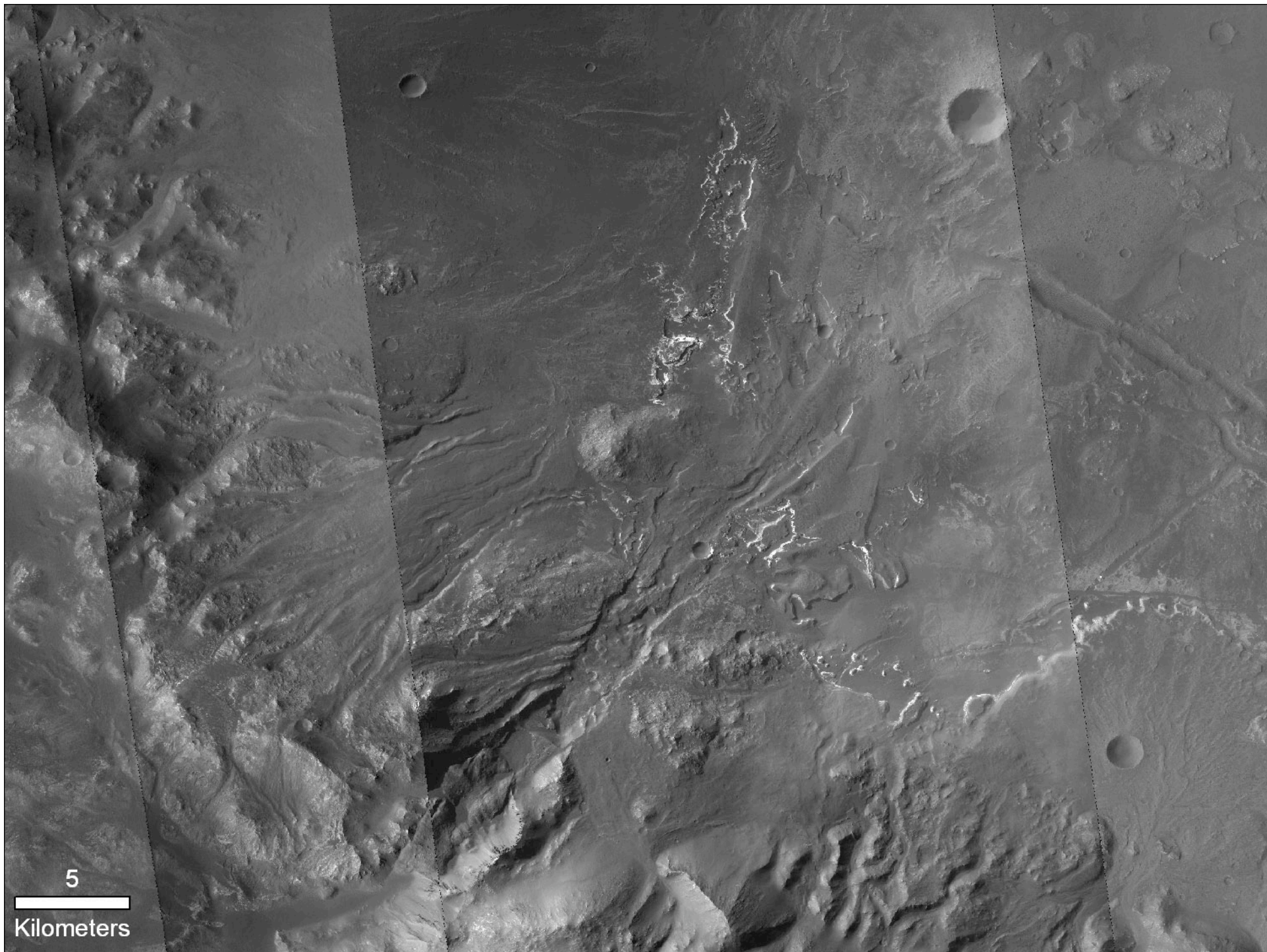


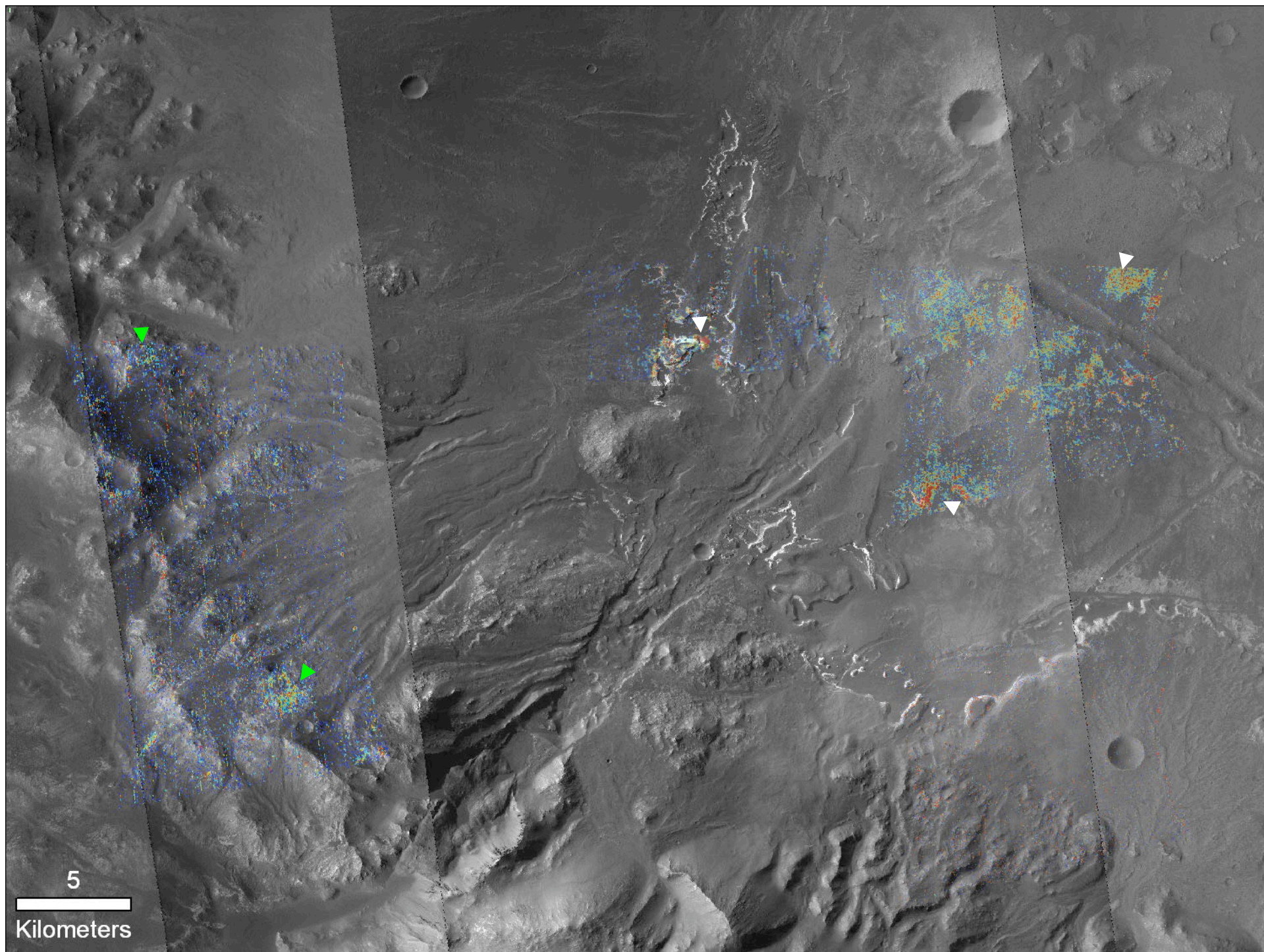
Mafic Minerals



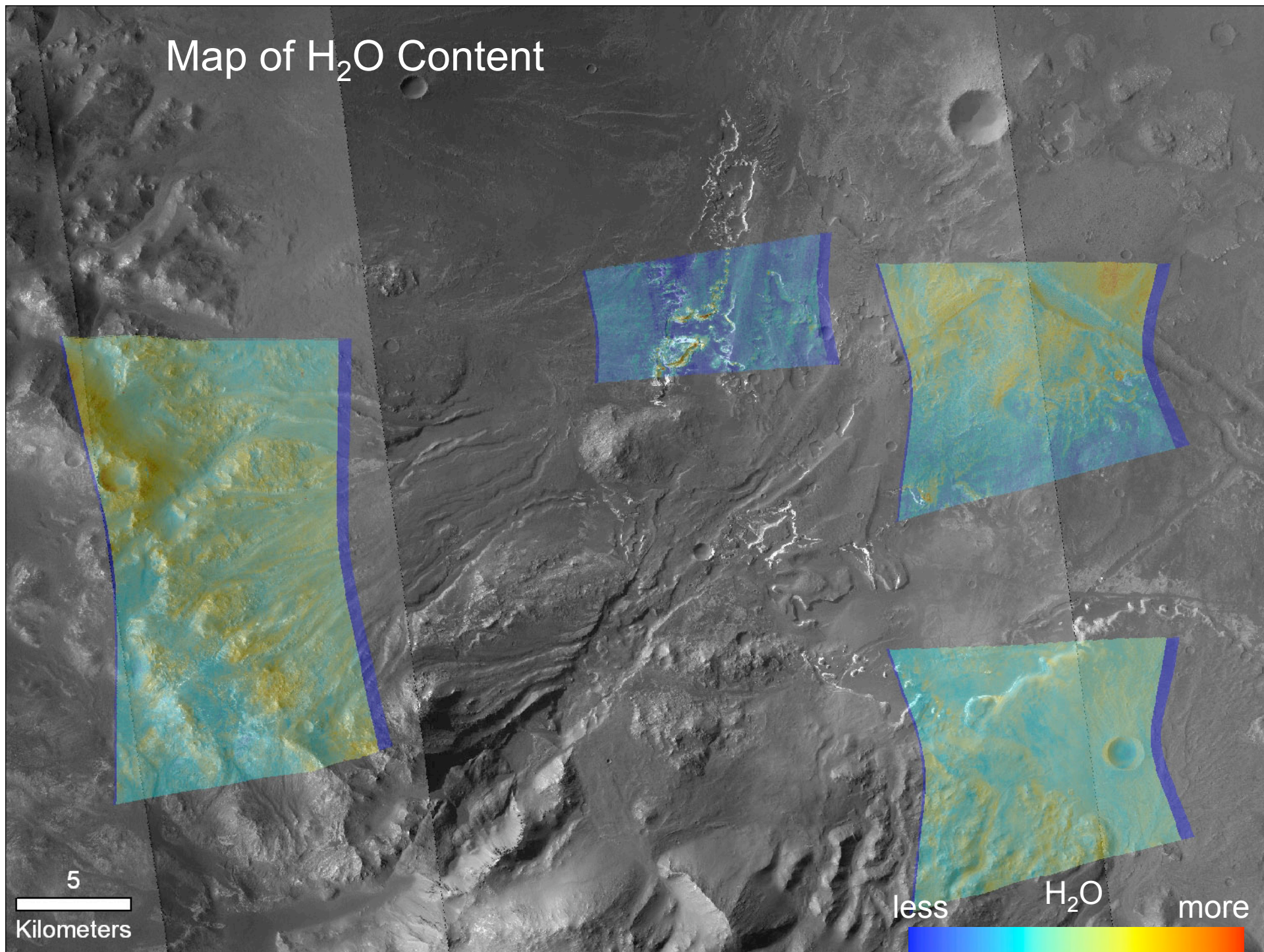
Clay Minerals

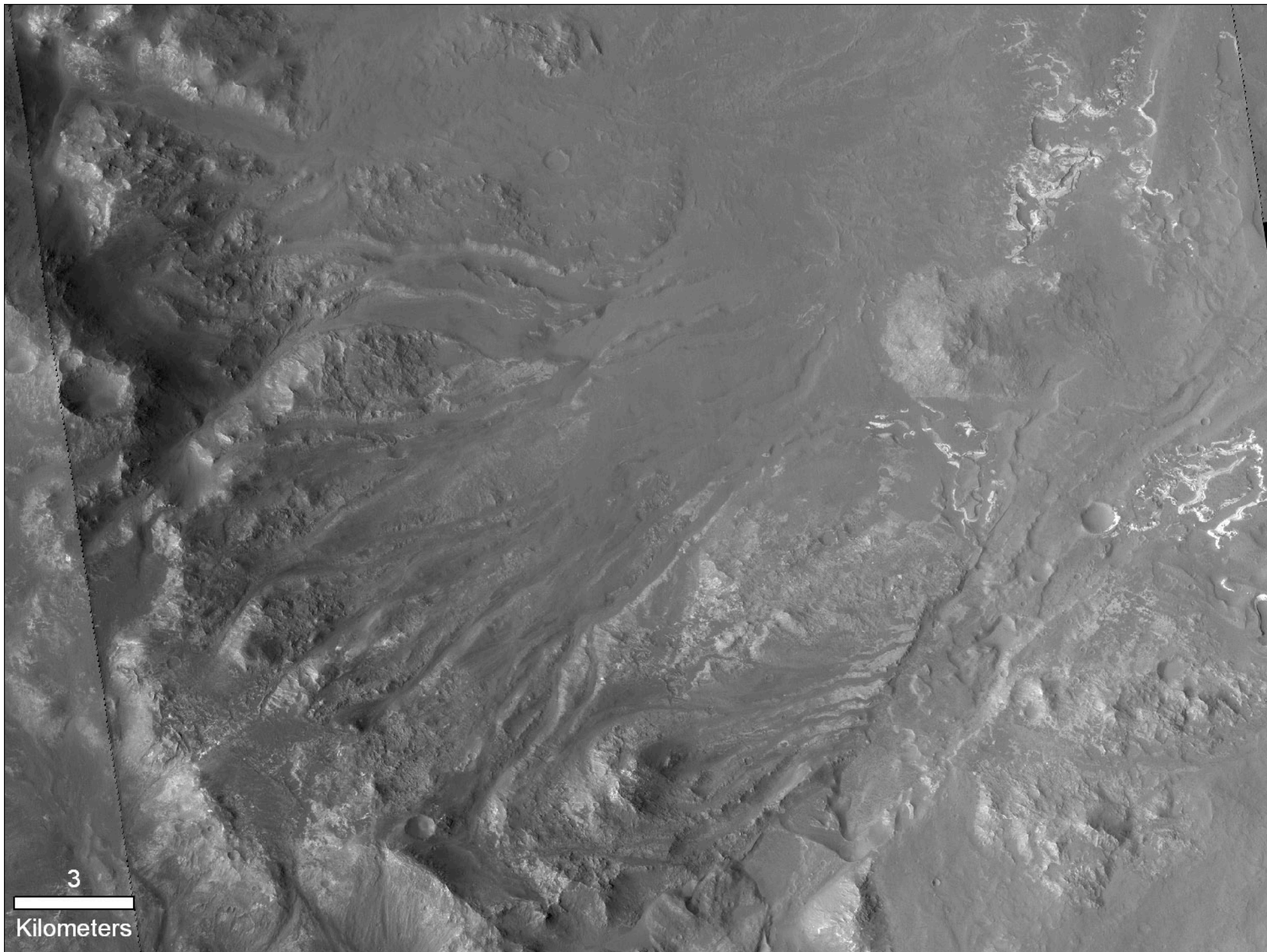


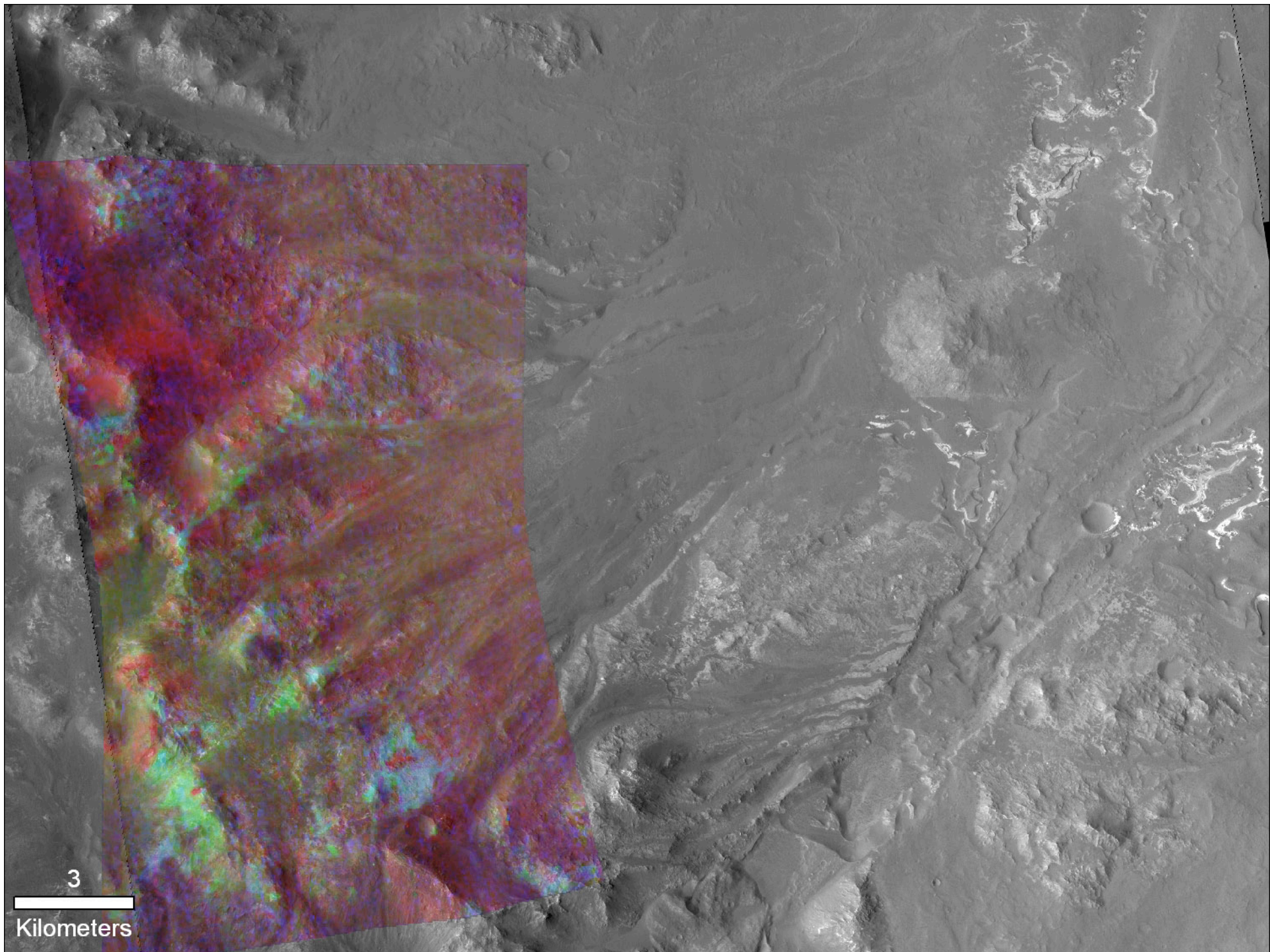


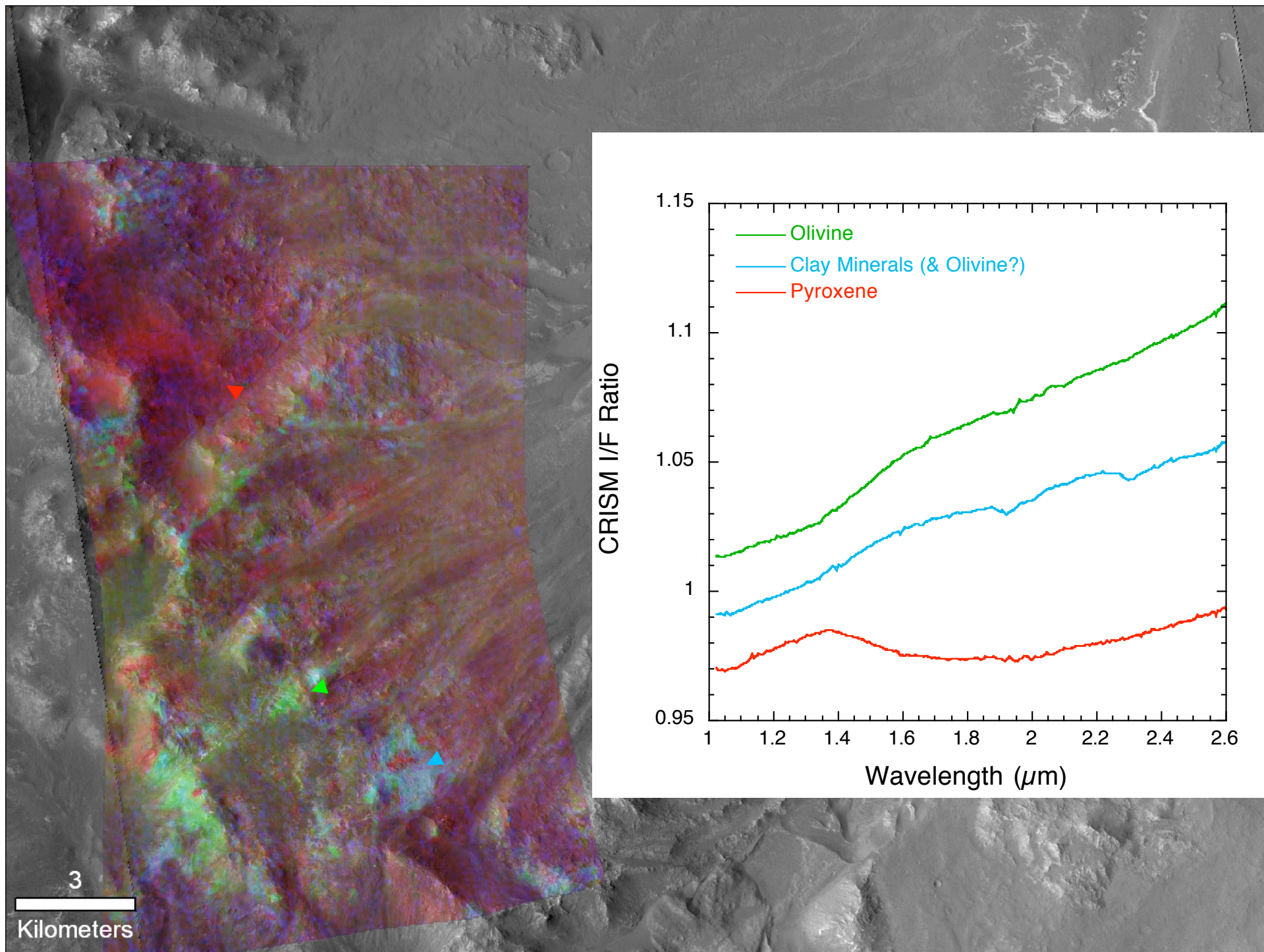


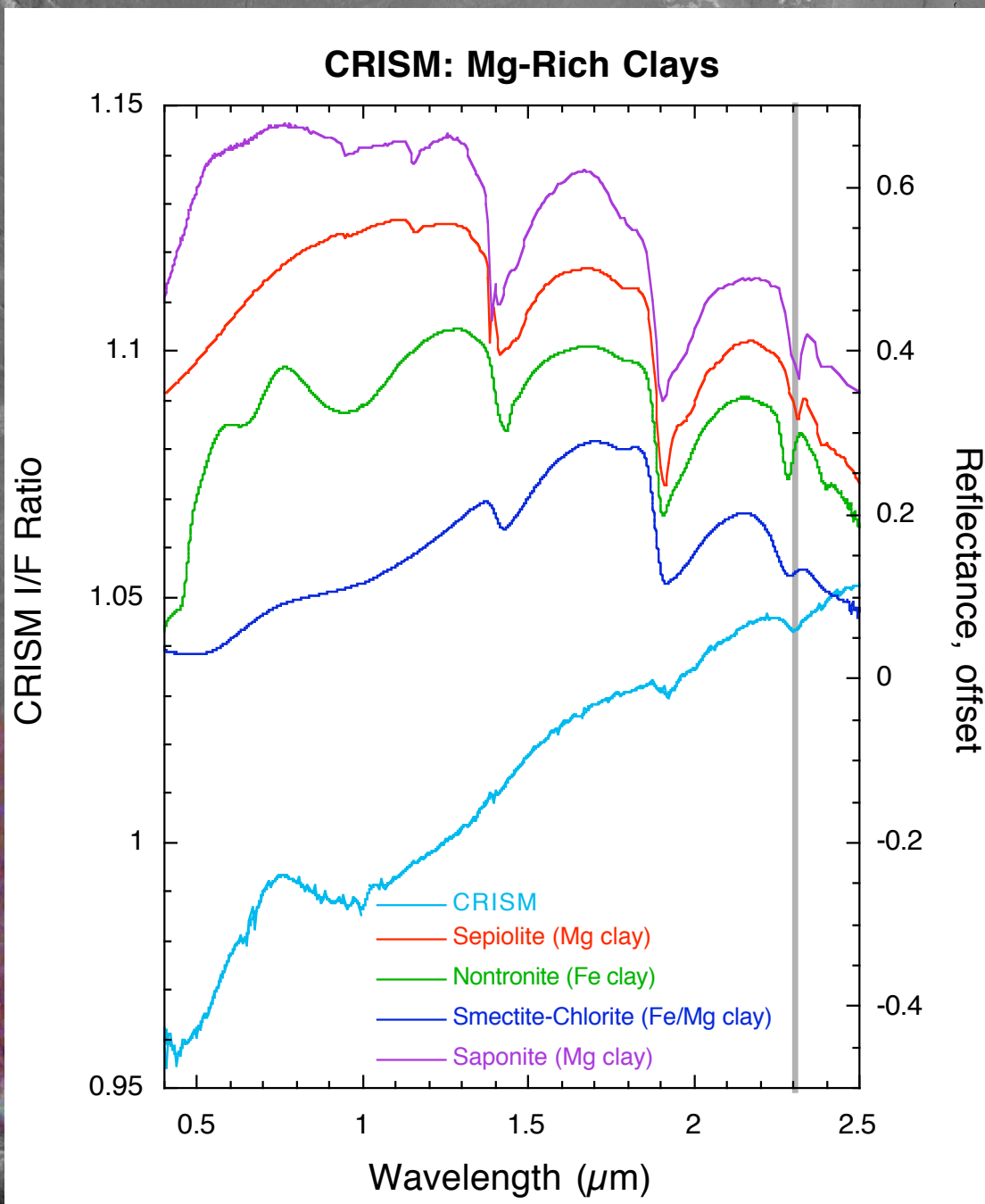
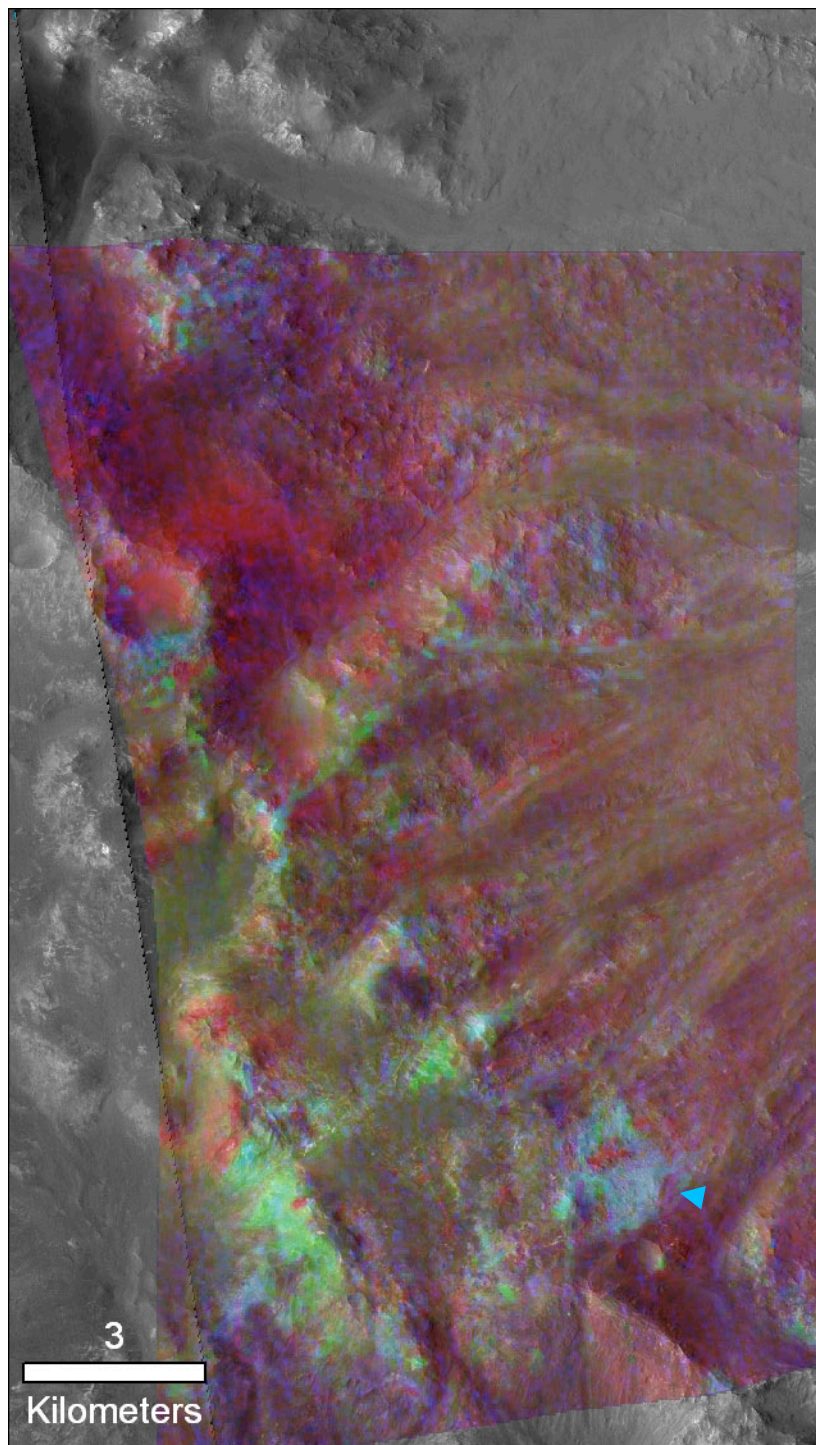
Map of H₂O Content











Stratigraphic Section of Deposits in SW Holden Crater

*morphology & sedimentary structures in the section can be quite variable from one fan to another
(section is based on *Grant et al.*, Geology, 2008)



HiRISE false color

Upper Unit

Lower Unit

Upper Member

- finely stratified (beds <10 m thick)
- individual strata are traceable for 100's m to ~1-5 km
- strata vary in albedo
- fractured, sometimes polygonal

Middle Member

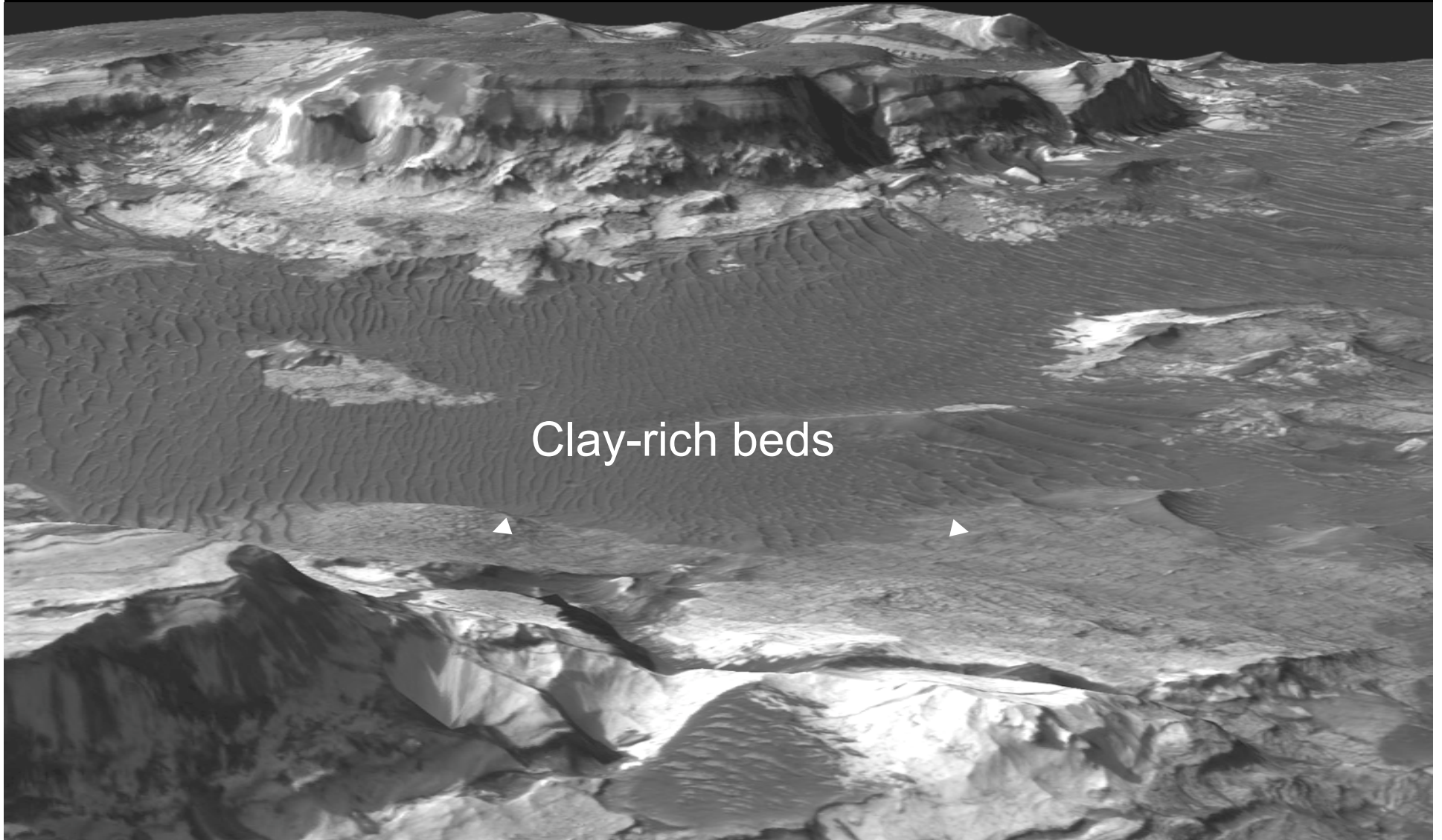
- massive to moderately thick strata (beds commonly >5 m)
- difficult to trace individual strata over 100's m
- bedding planes often exposed,
- suggesting some beds are tilted
- highly fractured w/ joint sets
- generally light-toned

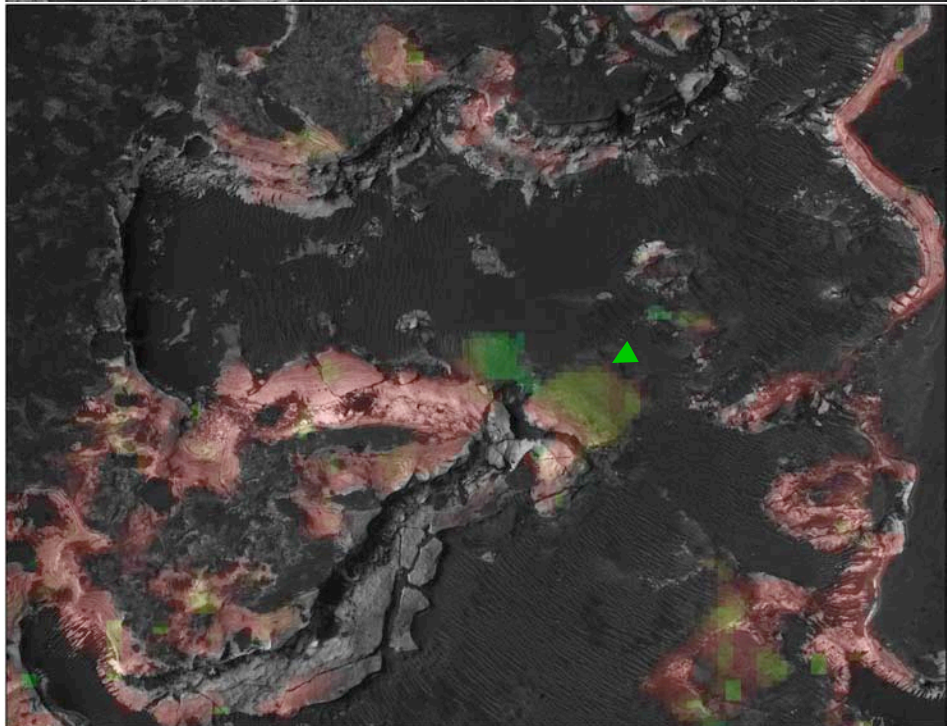
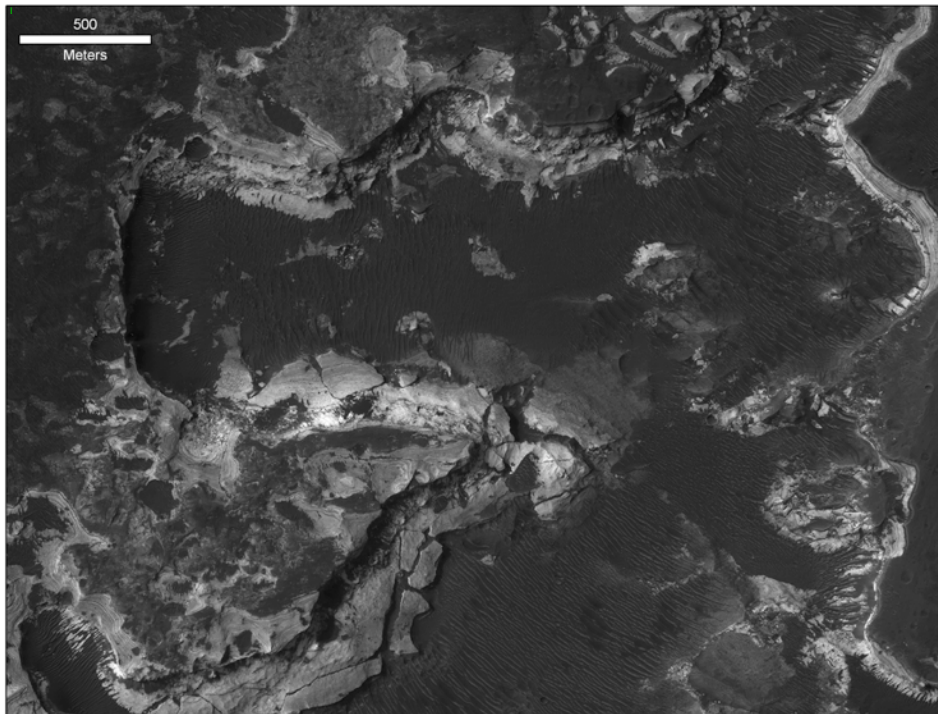
Lower Member

(not shown)

HiRISE DEM provided by
K. Lewis & O. Aharonson

Clay-rich beds

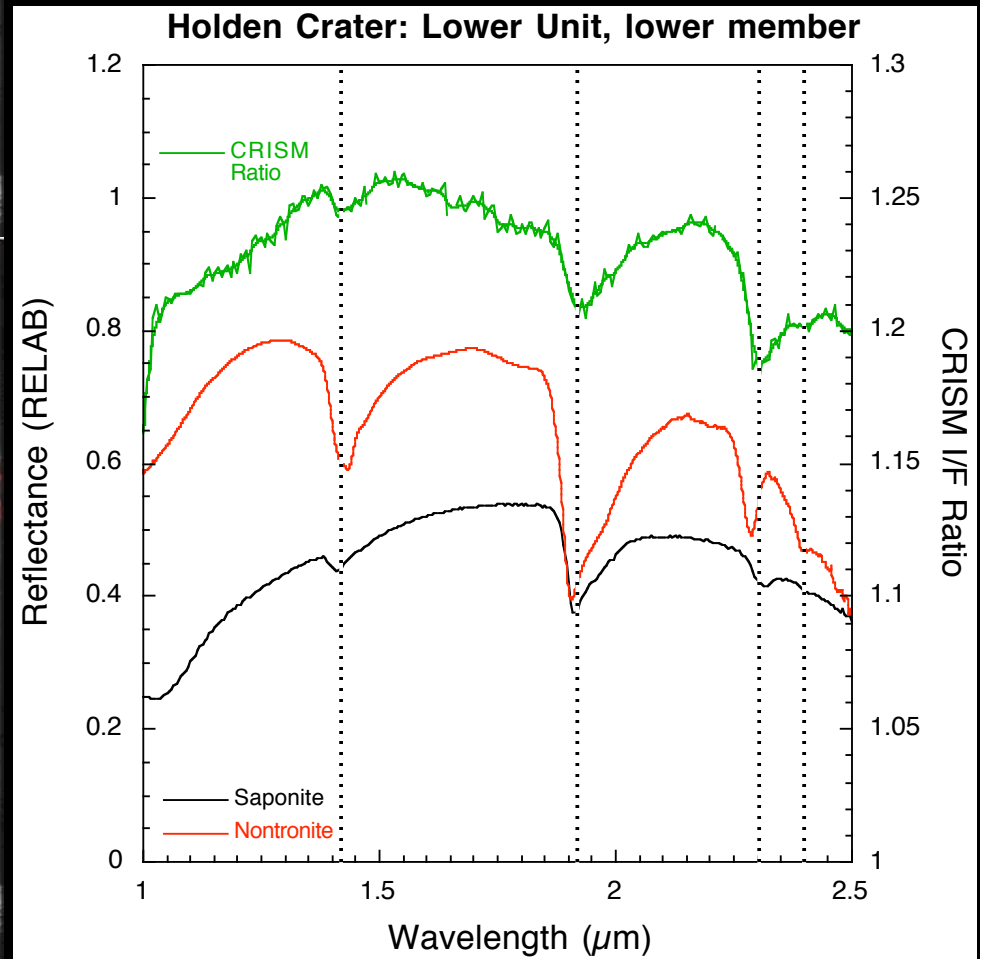


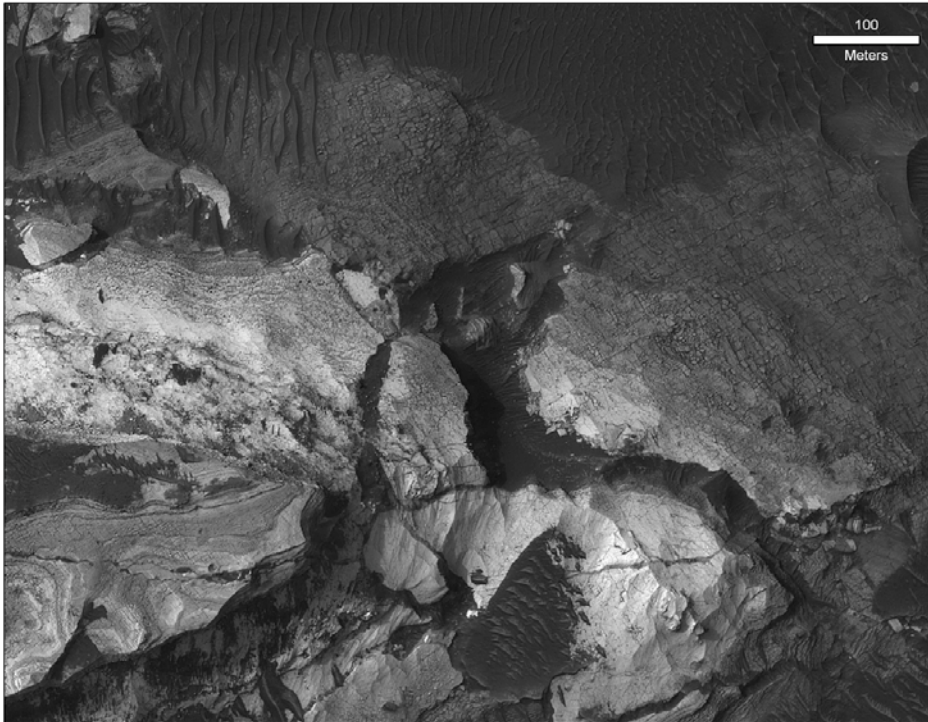


Spectral signatures are most consistent with **Fe/Mg-bearing smectites**, though it may also be a **mixed-layer smectite-chlorite**.

Strongest signatures are in intermediate albedo strata in the lower member of the lower unit.

Overlying strata exhibit weaker signatures and often lack a 1.9 μm H_2O feature.



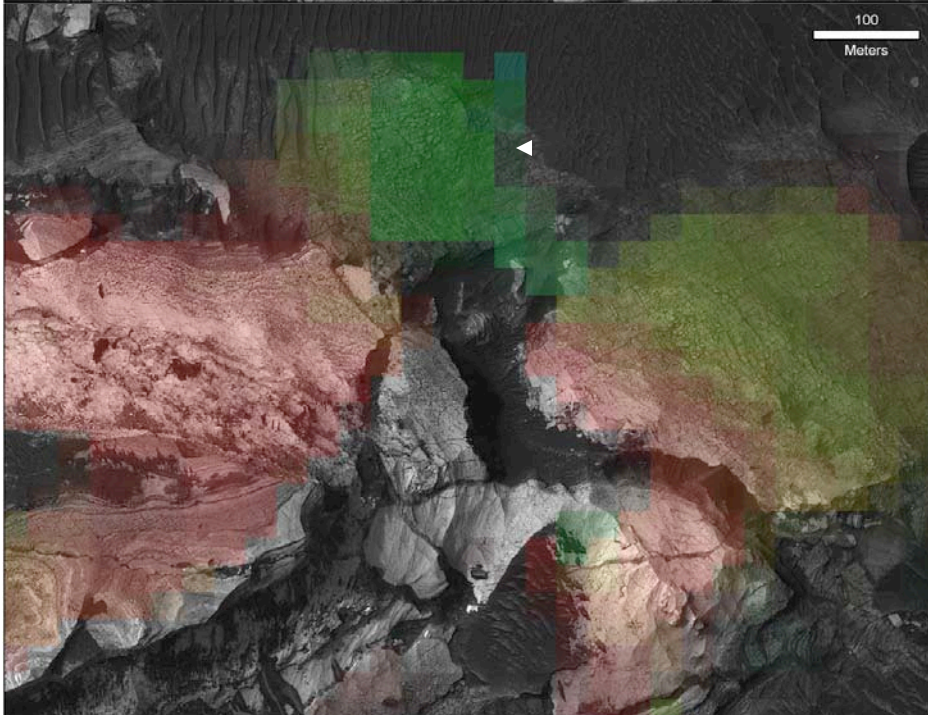


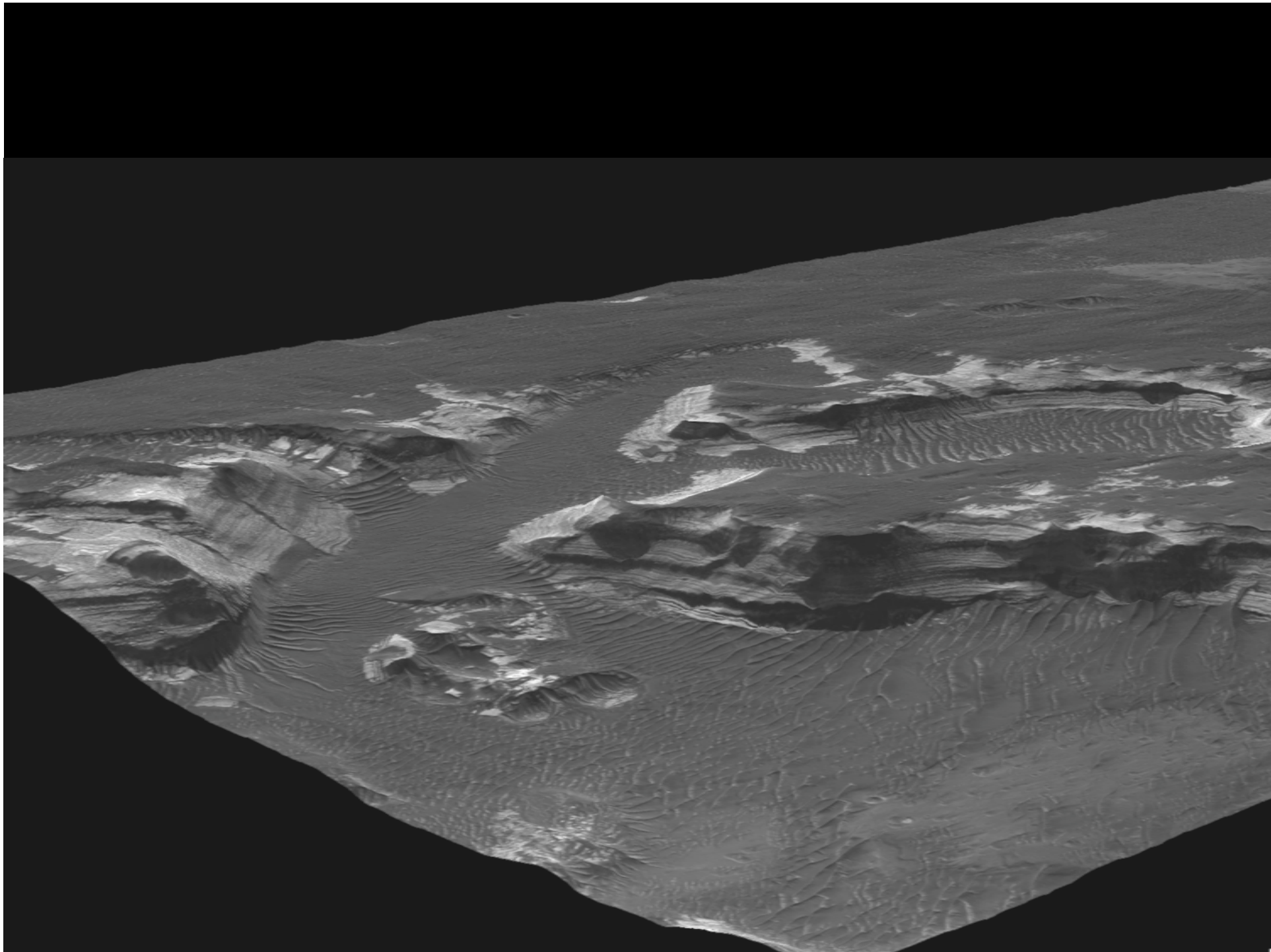
The phyllosilicate detections are most consistent with **Fe/Mg smectites**.

- phase contains H_2O
- phase exhibits metal-OH band at $\sim 2.3 \mu\text{m}$

These smectites are likely saponite or nontronite with some Fe-Mg substitution, or some mixture of these dioctahedral and trioctahedral Fe/Mg endmembers.

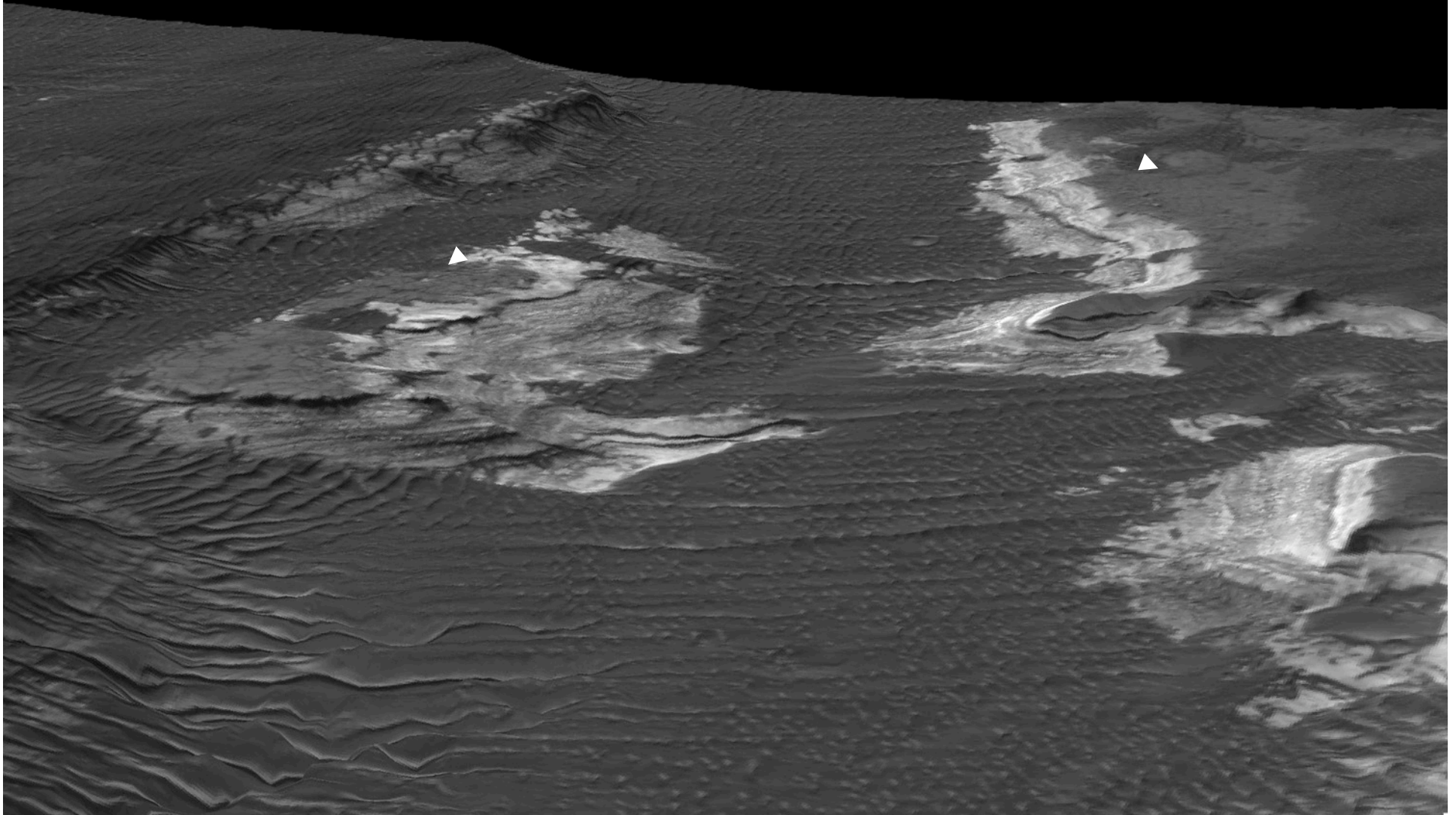
Materials with similar spectral properties are found in Eberswalde & Jezero deltas.

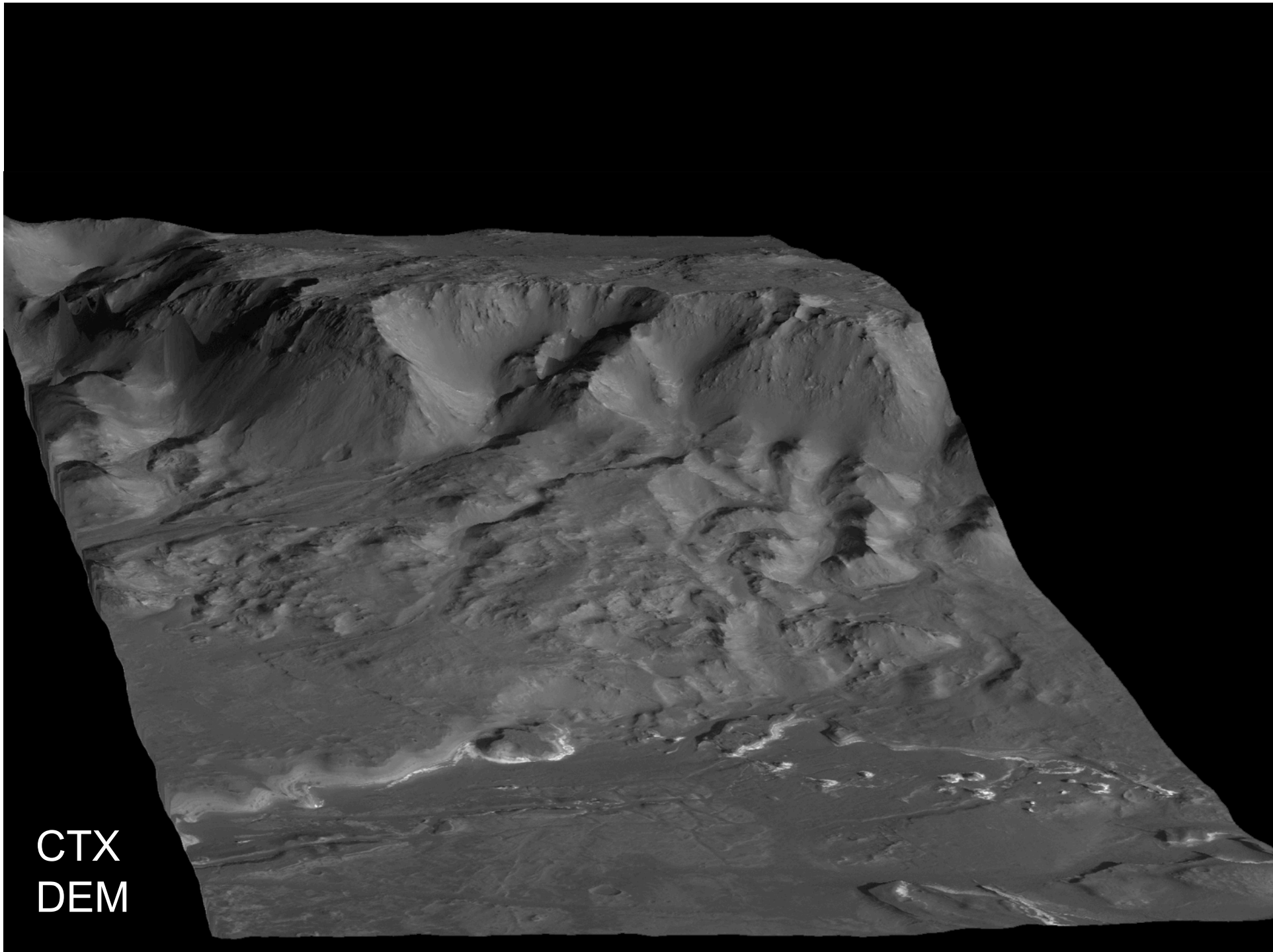




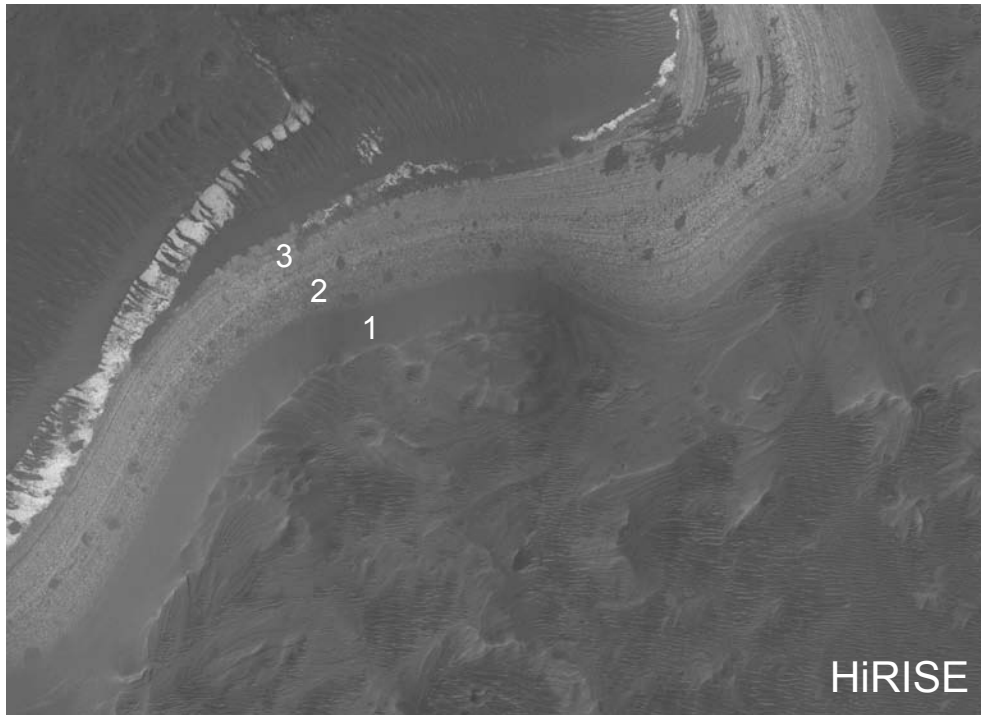
Upper member of the Lower Unit is capped by a dark bed exhibiting polygonal fractures.

This material is clay-bearing when observed in CRISM data.





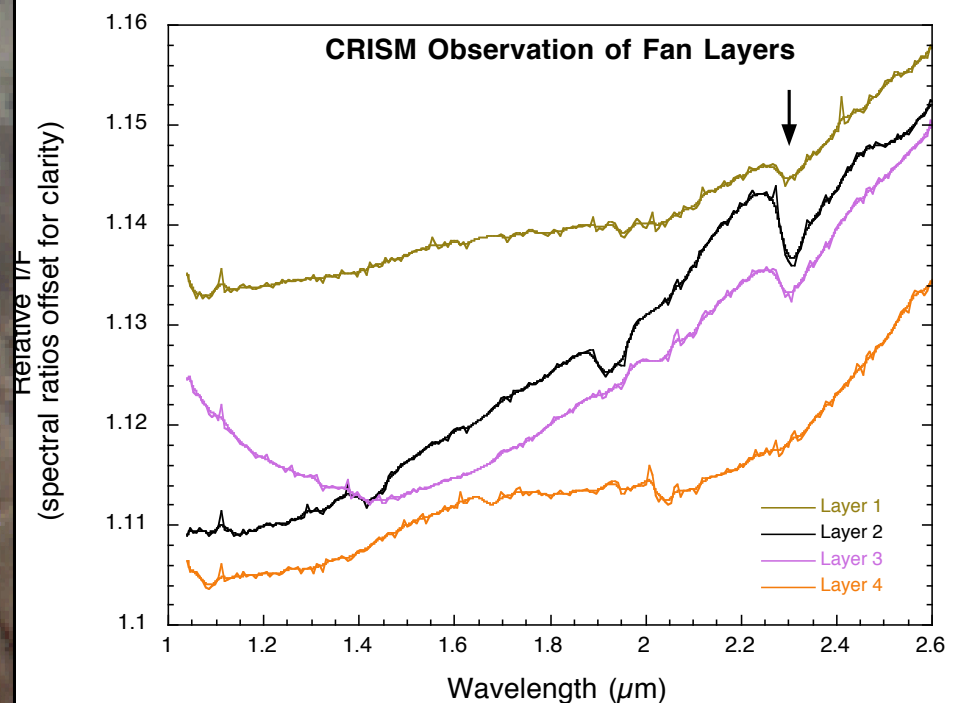
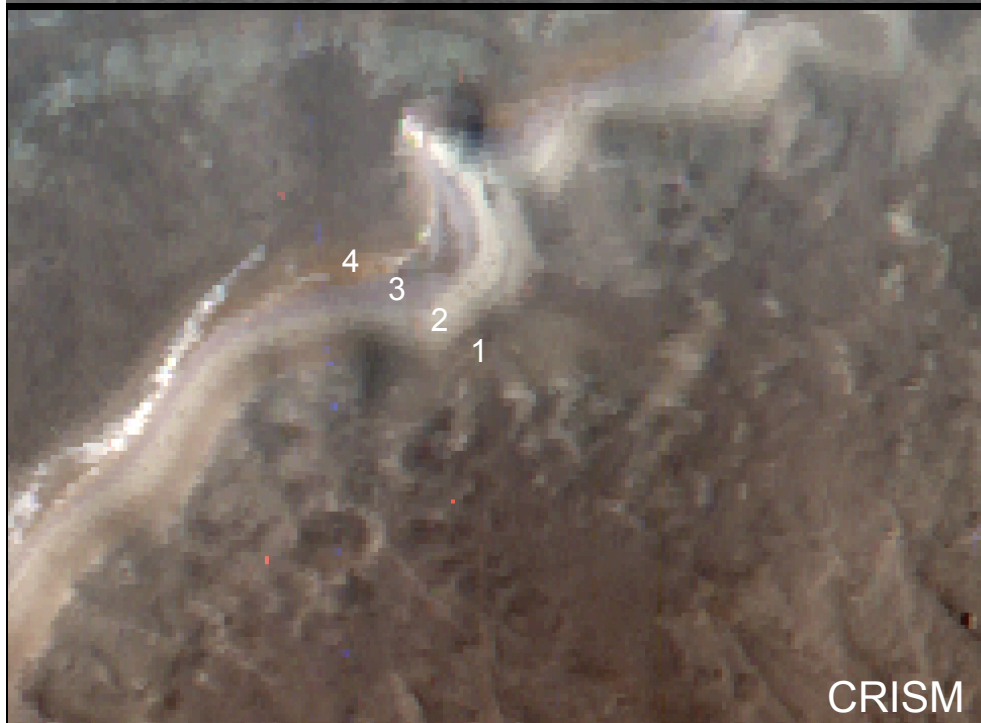
CTX
DEM



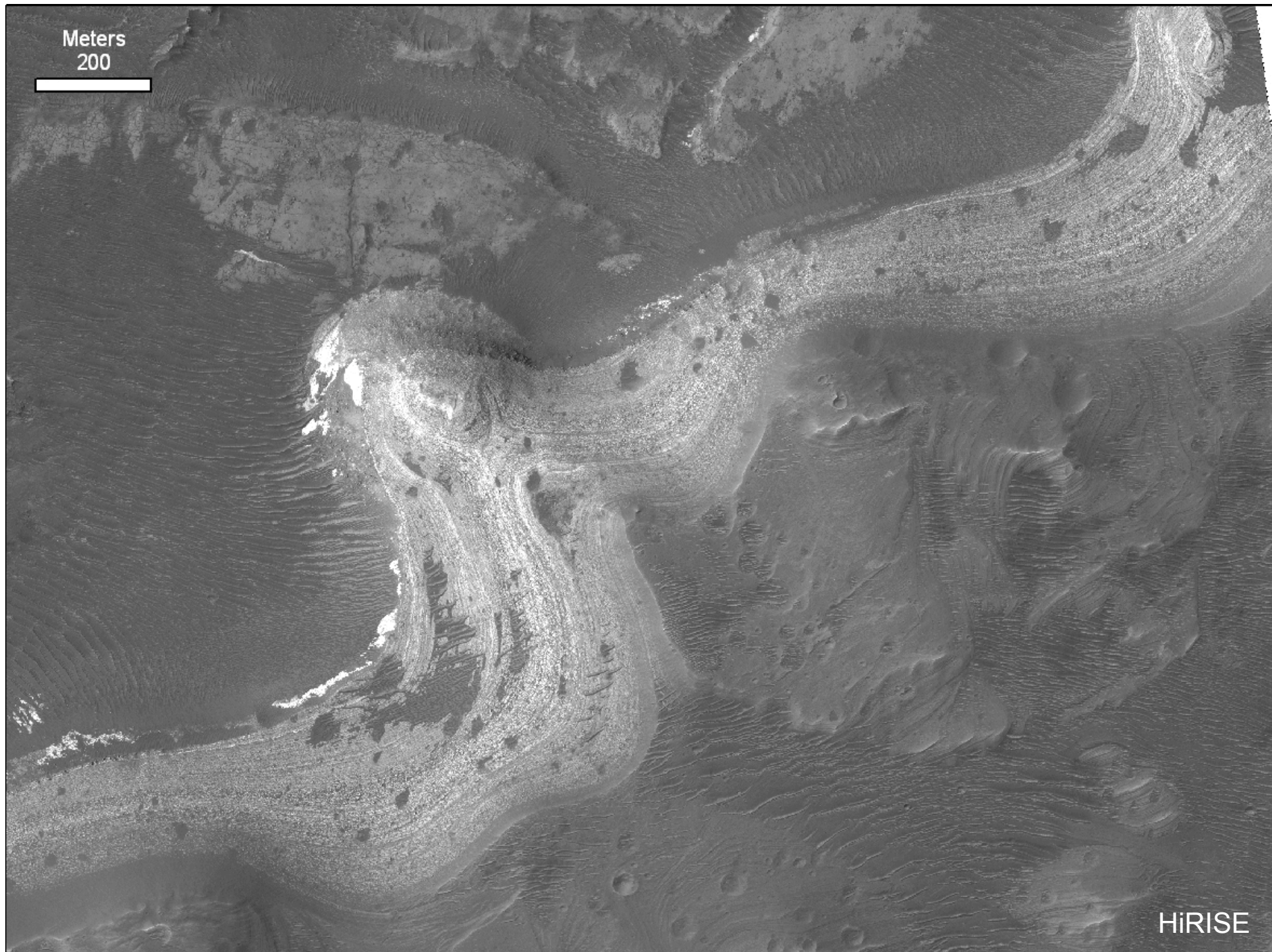
Fe/Mg phyllosilicates are detectable in all but the lowest layers in the fan deposit.

Strongest signatures correlate to middle units, weak signature in uppermost unit.

Only the middle layers exhibit clear evidence of a $1.9 \mu\text{m}$ (H_2O) band.... but this is a weaker band than the fundamental stretches near $3 \mu\text{m}$, so what do we see at $3 \mu\text{m}$?



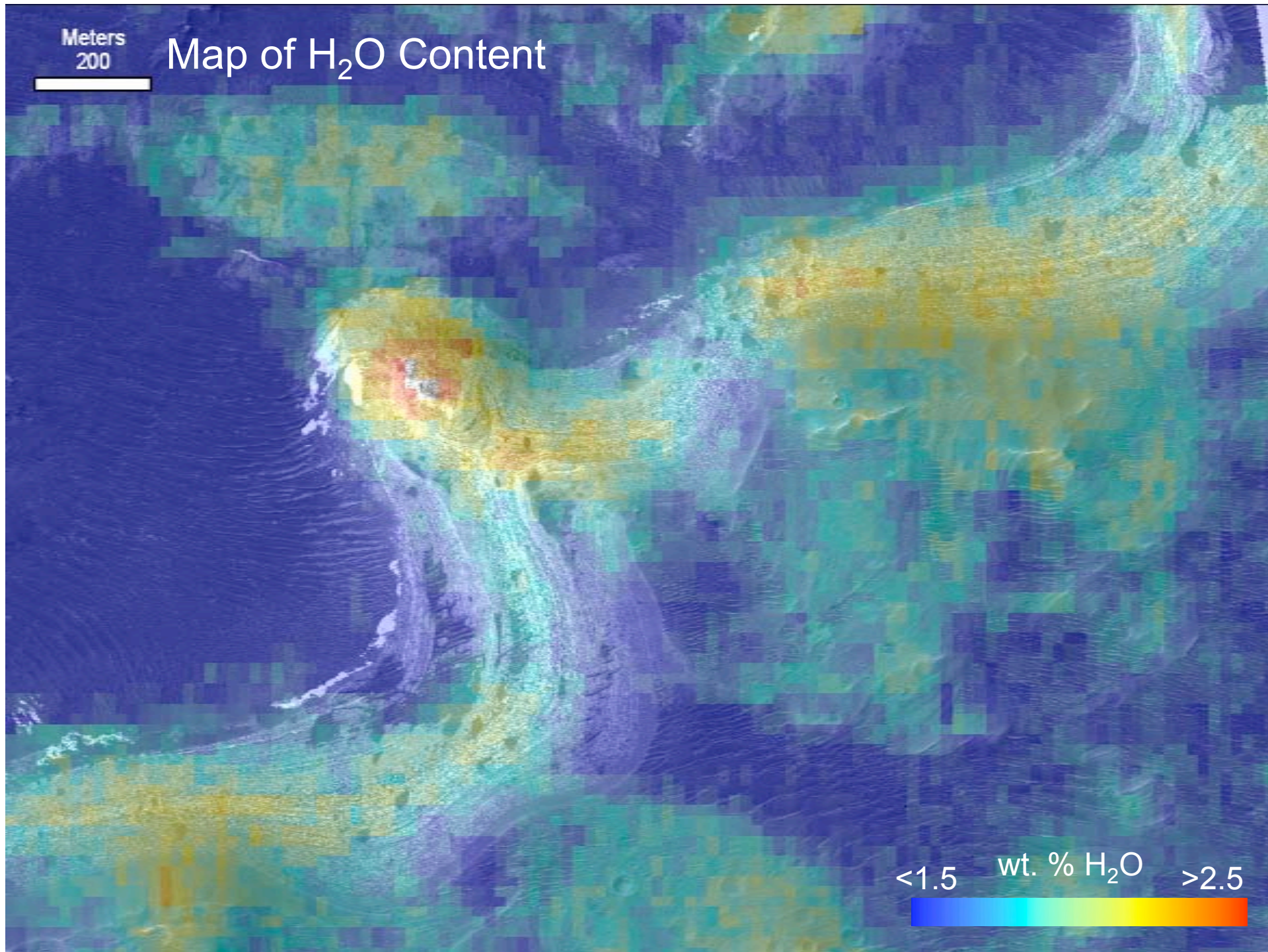
Meters
200



HiRISE

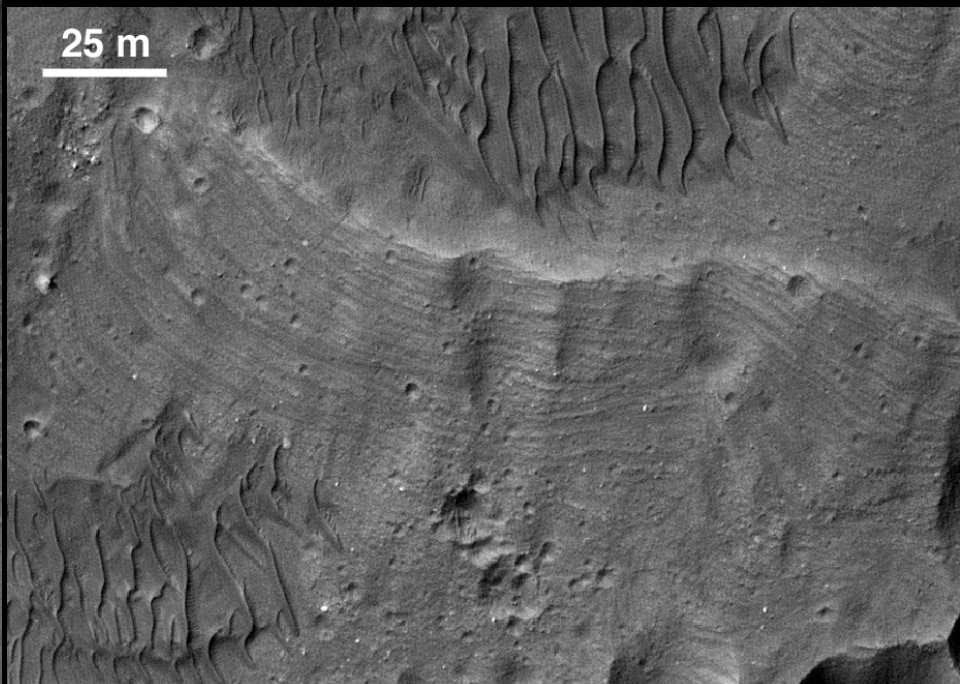
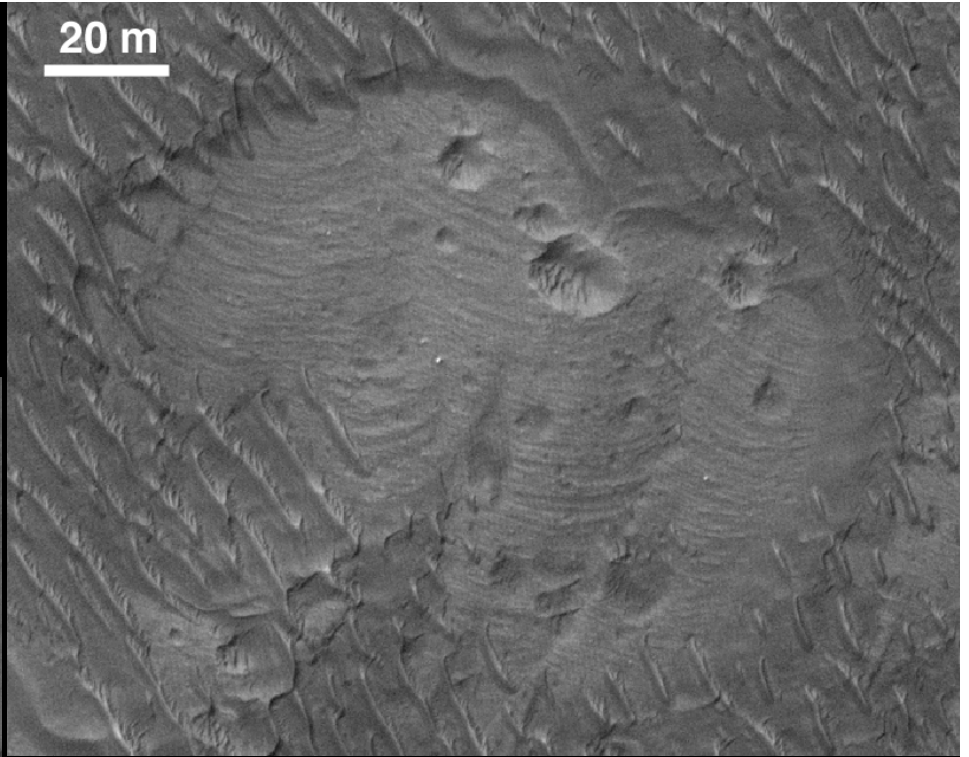
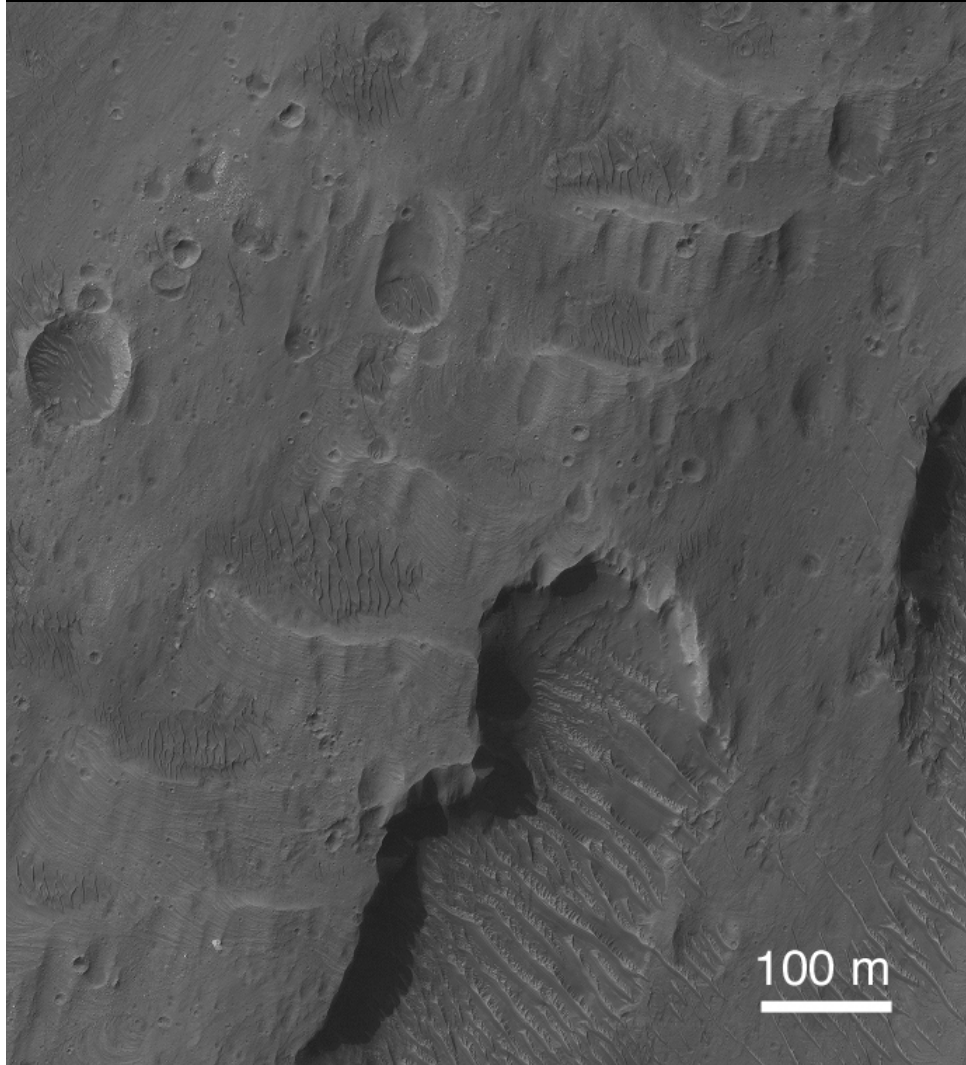
Meters
200

Map of H₂O Content



Fluvial features in Upper Unit suggest a **high-energy flooding event** associated with Uzboi breaching the crater rim (duneforms, rib & furrow, large clasts).

Paleocurrent is aligned with Uzboi breach.



THE MINERALOGY OF HOLDEN CRATER

CRISM images in the ellipse are noisy....no clear detection of clays in ellipse.

However, CRISM images of similar morphologic units do exhibit weak clay signatures and clays are clearly weathering out of the crater rim.

- Some of the clays in Holden Crater are detrital (transported from rim).
- Alteration of olivine and pyroxene in crater rim consistent with Mg/Fe smectites
- Some of the clays may have formed in sedimentary environments in the older Holden Basin prior to the formation of Holden Crater.

There are thick sequences in Holden Crater that most likely record a history of alluvial, fluvial, and lacustrine (?) processes.

There are clear variations in the strength of clay signatures through the stratigraphic section: clays tend to decrease in abundance from bottom to top.

Deposits related to the Uzboi flooding event contain clay minerals.

Clay signatures are strongest in the lowermost units.

- These clay units have shallow slopes & erode easily....Martian mudstones?

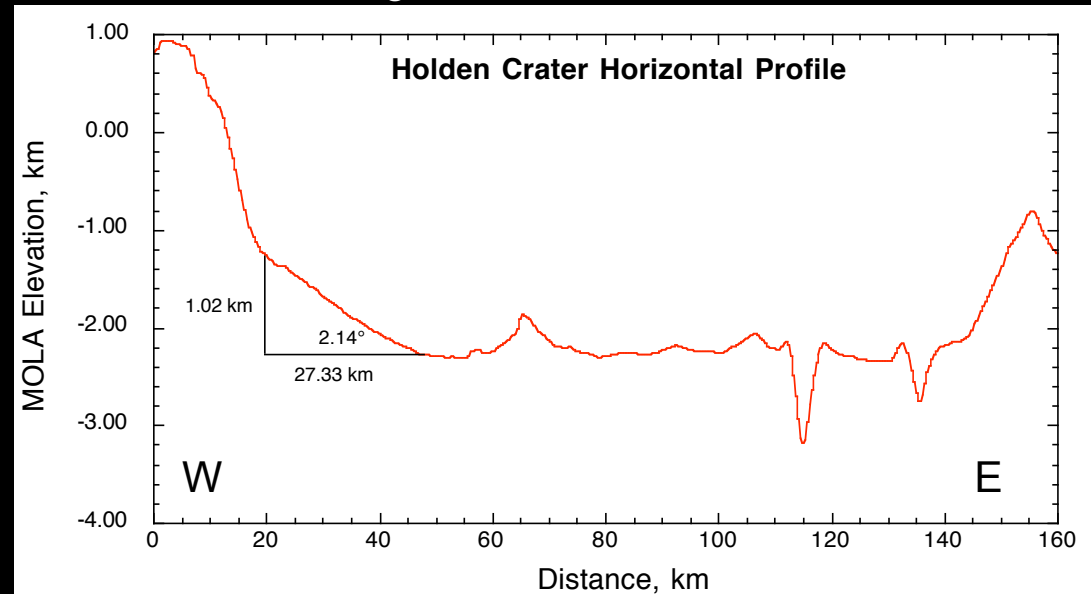
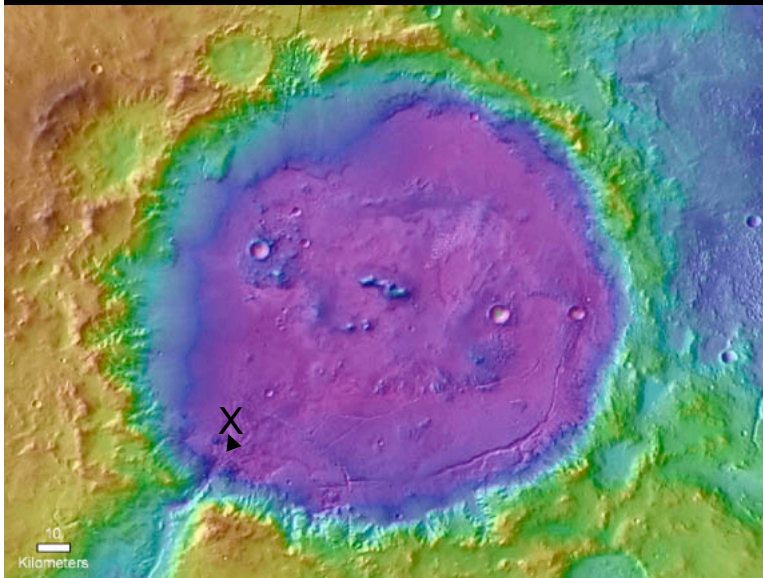
Alluvial fans along western edge of Holden Crater exhibit surface slopes $<2.5^\circ$.

These fans extend 10's km into the crater and cover the lower unit in these regions.

- outcrops of the light-toned lower unit are rare except in the SW portion of the crater

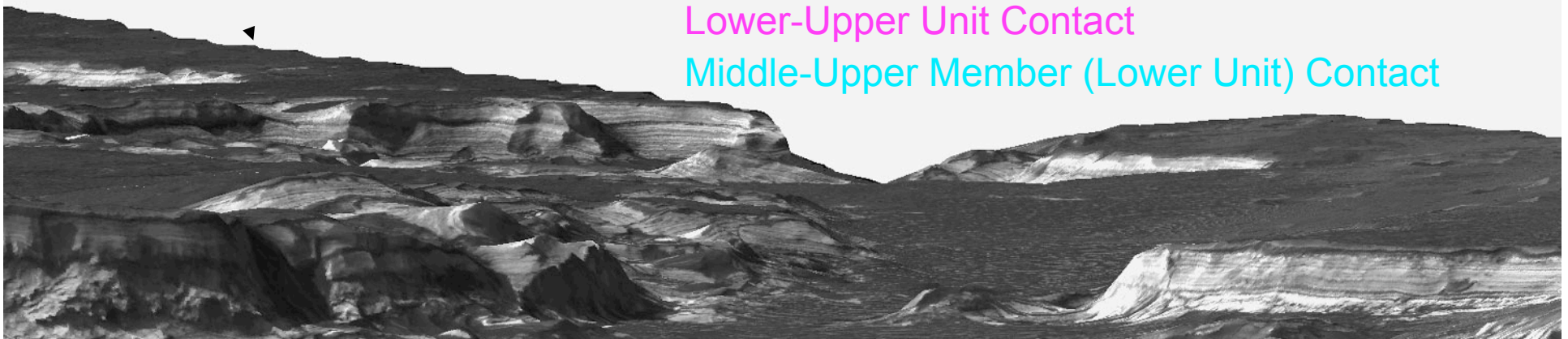
The contacts between units also exhibit shallow dips

- majority of beds do not appear to be truncated on short length scales

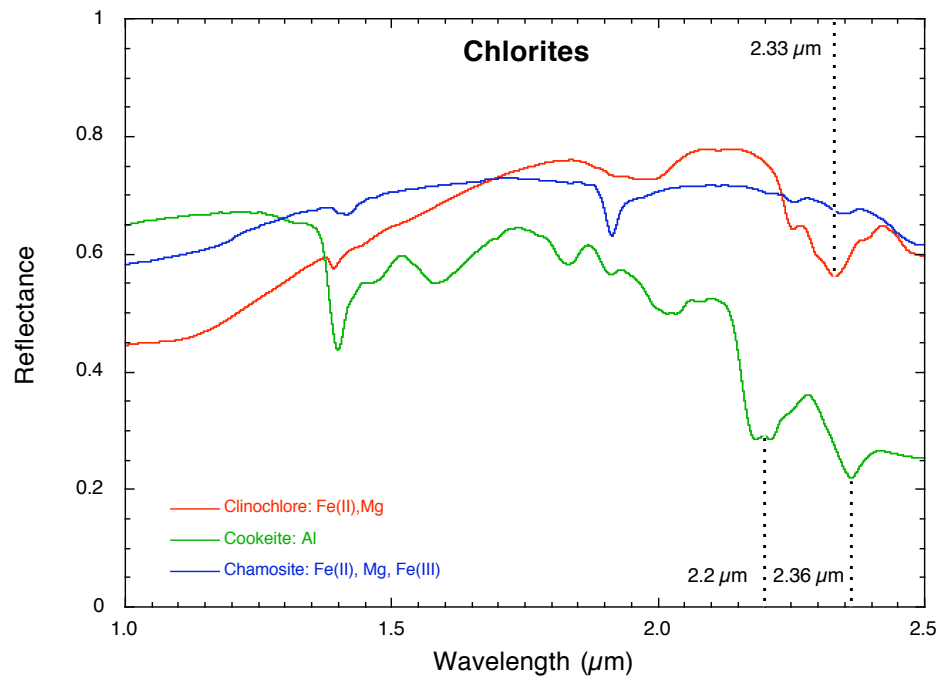


Lower-Upper Unit Contact

Middle-Upper Member (Lower Unit) Contact



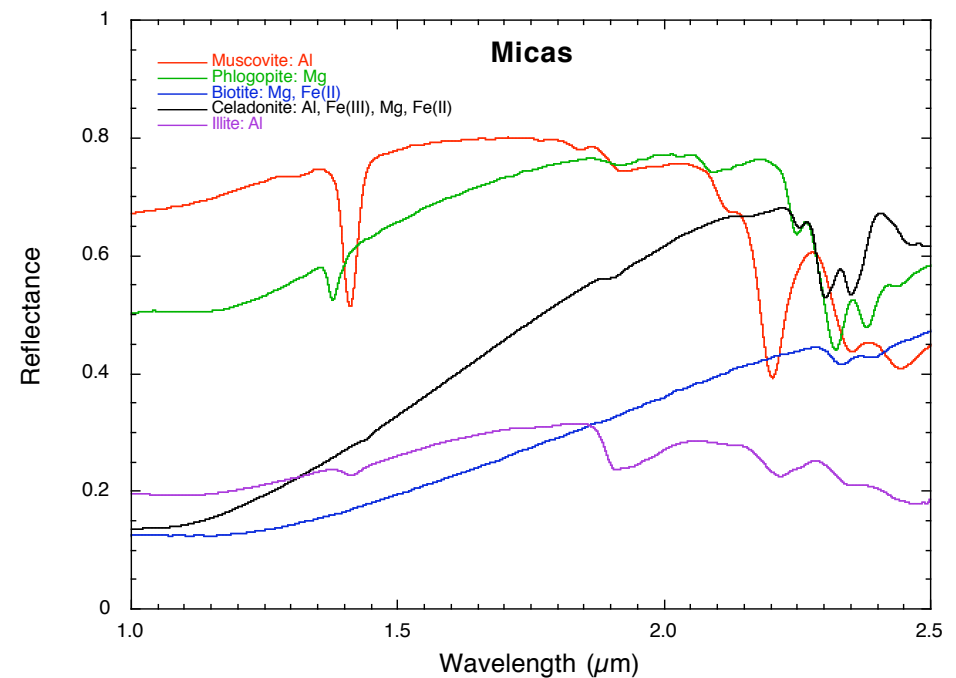
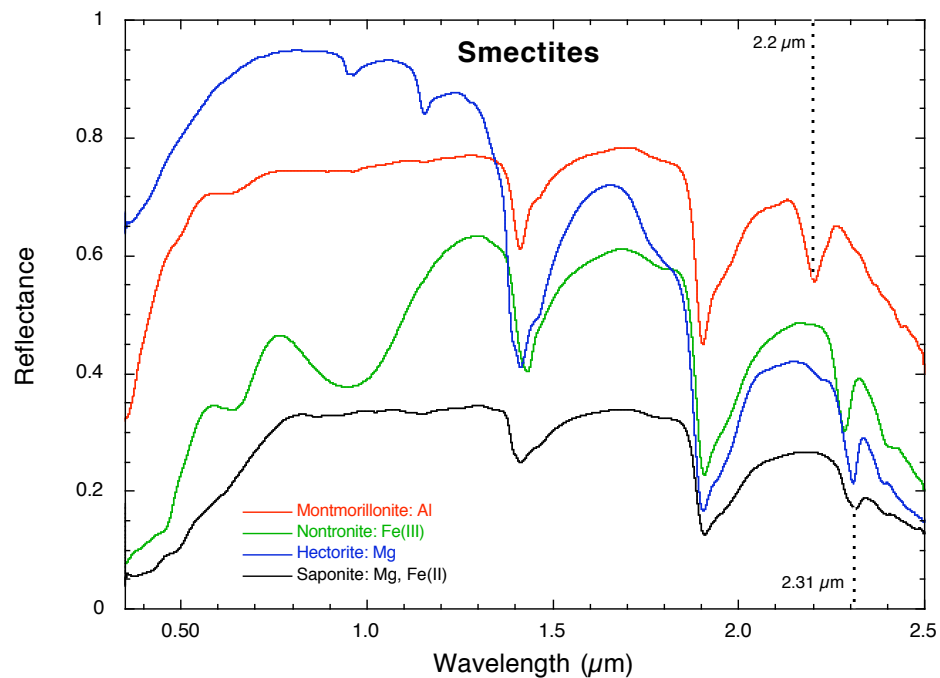


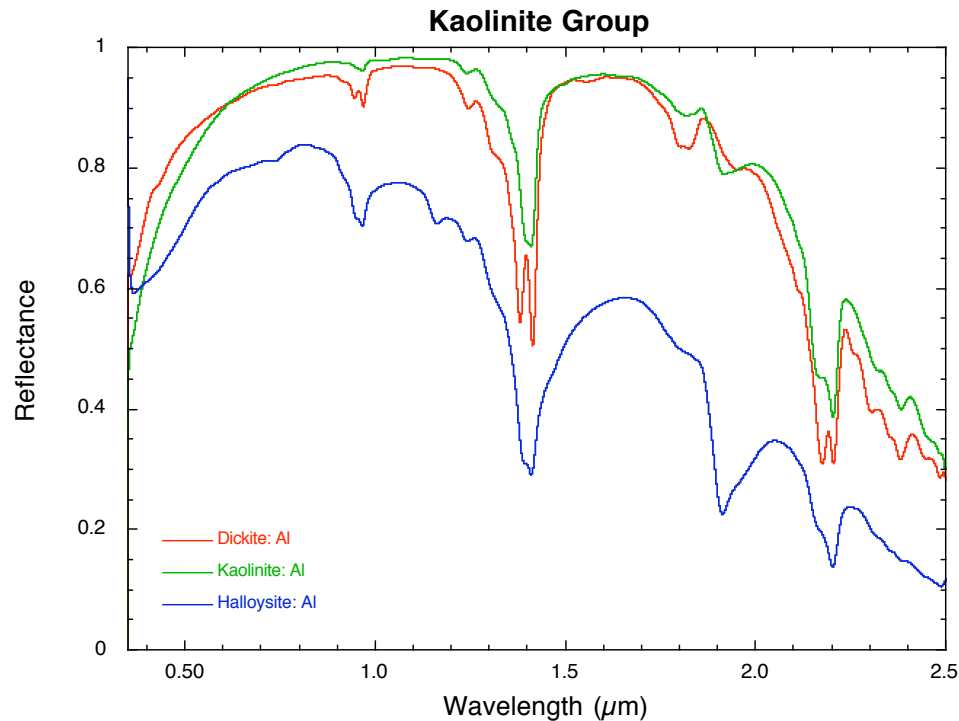


VIS-NIR reflectance spectra can be used to distinguish between major phyllosilicate groups:

- kaolinite, serpentine (1:1, 7Å)
- smectites, micas (2:1, 10Å)
- chlorites (2:1+1, 14Å)

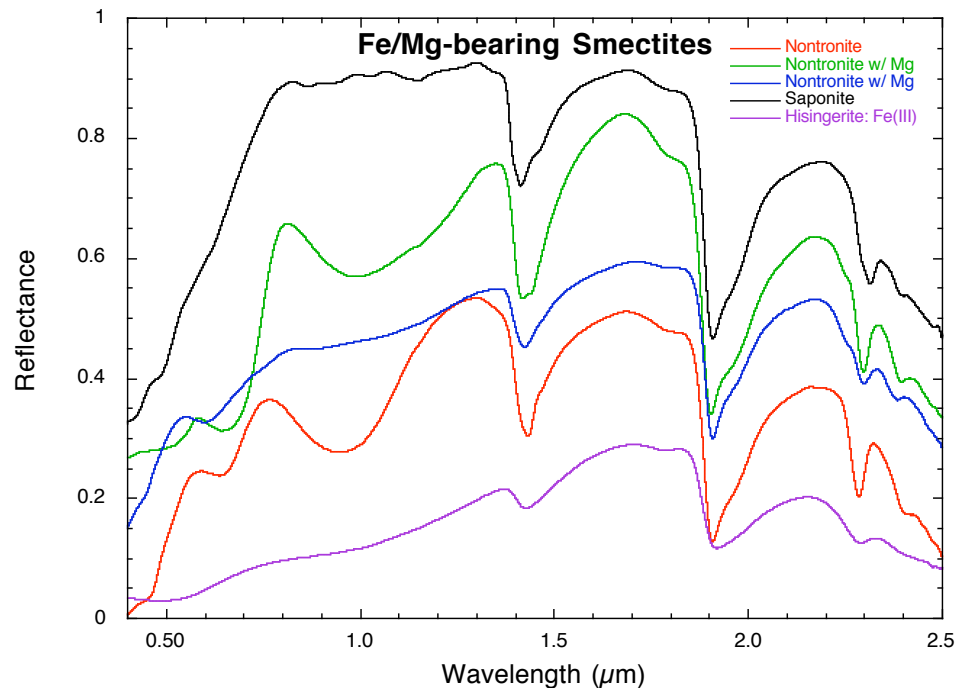
However, there are some potential sources of confusion for distinguishing between different minerals *within* the groups.





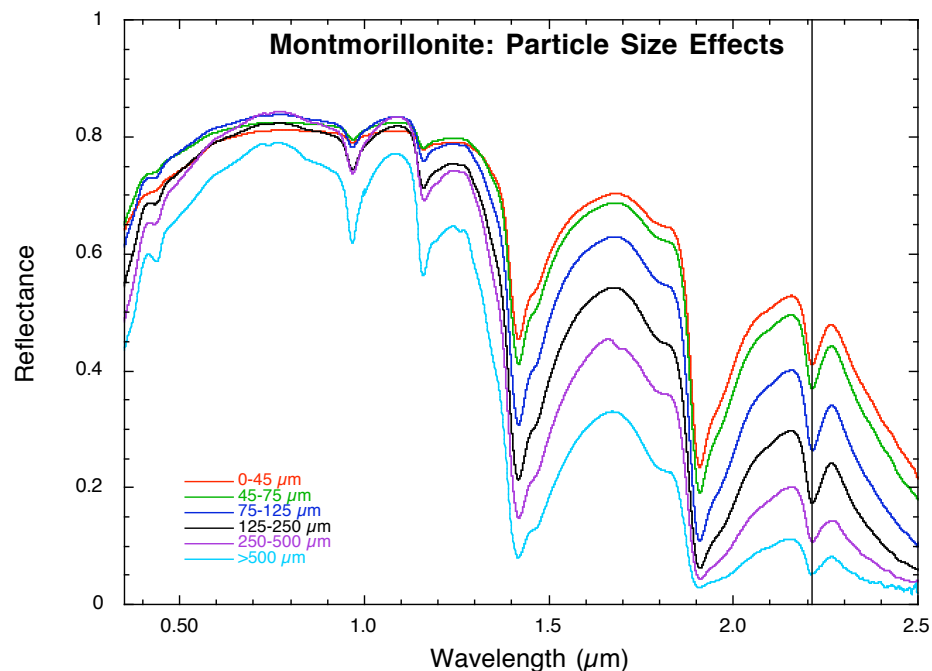
Using CRISM and OMEGA, we should be able to distinguish kaolinite from dickite (high-temp polymorph)...

but it may be difficult to tell the difference between halloysite and kaolinit e+hydrated mineral



We can also tell the difference between Al-rich smectites and Mg/Fe-rich smectites...

but it may be difficult to tell the difference between the various types of Mg/Fe smectite due to cation substitutions.

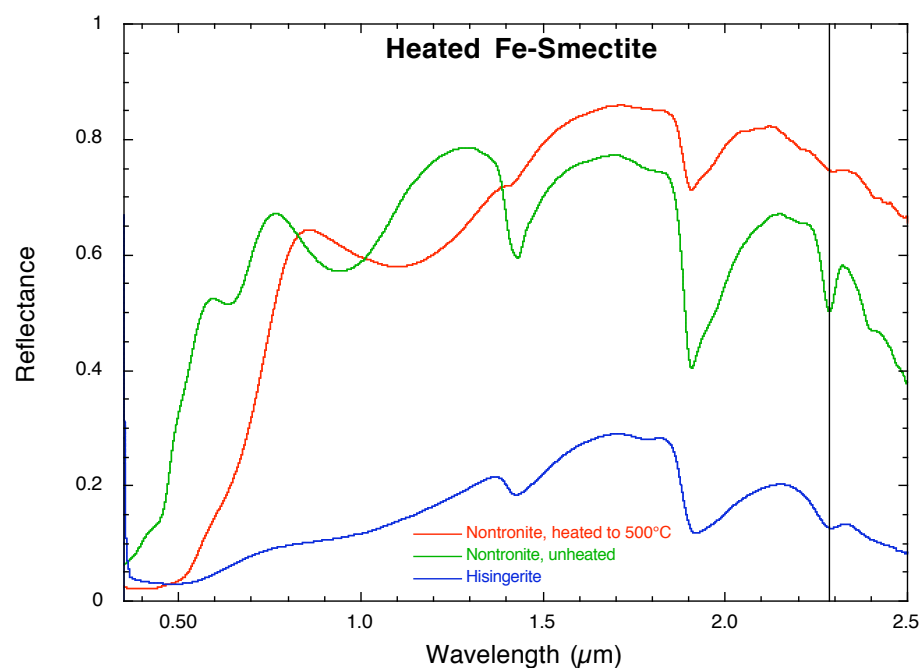
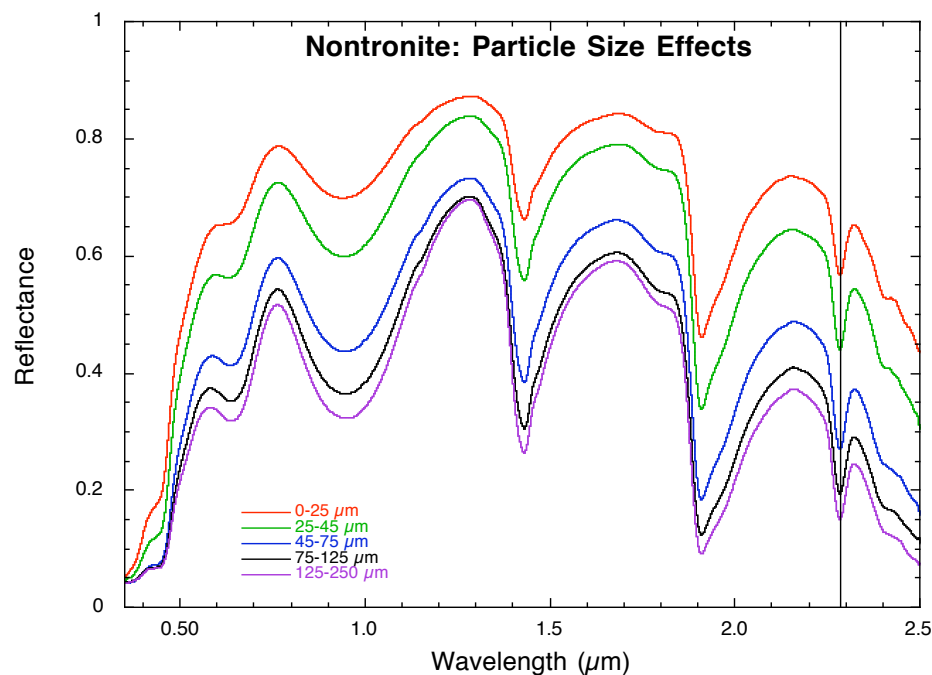


Particle Size

- does not have noticeable effect on position of specific bands
- spectra of large particles may lose weaker bands at long wavelengths (illite vs mont.)
- band strength is not necessarily directly comparable to clay abundance

Loss of H₂O and/or OH

- 1.9 μm H₂O band can disappear; reversible
- interlayer region can collapse; irreversible
- can lose metal-OH bands
- heating can oxidize Fe or change structure



Laboratory measurements have shown that it is possible to estimate the H₂O content of various hydrated phases to within ≤ 1 wt. % for a wide variety of phyllosilicates, zeolites, sulfates, and hydrated volcanic materials.

[Milliken and Mustard, 2005; 2007a; 2007b; 2007c]

Preliminary results for CRISM show that the phyllosilicate bearing units have 2-3 times more H₂O than dusty regions, similar to OMEGA results.

* absolute values may change as thermal and instrumental corrections are updated

